CHARACTERIZATION OF LOCAL SAND FOR POSSIBLE USE AS PROPPANT

SUHAILA MUHAMAD

CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS

JULY 2009

Characterization of Local Sands for Possible Use as Proppant

by

Suhaila binti Muhamad

Dissertation submitted in partial fulfillment of
The requirement for the
Bachelor of Engineering (Hons)
(Civil Engineering)

December 2009

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan
Malaysia

CERTIFICATE OF APPROVAL

Characterization of Local Sand for Possible Use as Proppant

by

Suhaila binti Muhamad

A project dissertation submitted to the Civil Engineering Program
Universiti Teknologi PETRONAS in partial fulfillment of the requirement for the
Bachelor of Engineering (Hons) (Civil Engineering)

Approved by,

AP Dr. Ismail Mohd Saaid 21/12/09

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2009

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken nor done unspecified courses or persons.

SUHAILA BINTI MUHAMAD
870530-14-5506
ID: 7733
UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

ACKNOWLEDGEMENT

In the name of God, The Nourisher, The Ever-Provider.

Praise to God for His guidance, blessing and borrowed time which have fueled me throughout this entire project.

My profound appreciation and gratitude is extended to my supervisor, AP Dr. Ismail Mohd Saaid for his advices, encouragements, and constructive comments. I am utterly honoured to be under his leadership in achieving this project's goals. Without his support, it would be impossible for this project to be completed.

I would like to extend my gratitude to Dr. Chow Weng Sum for his guidance especially during the first semester of my Final Year Project.

Not to forget, special thanks to all the technicians from Civil, Geosciences and Petroleum, and Mechanical Engineering departments of Universiti Teknologi PETRONAS for their assistance and help both directly and indirectly.

I would also like to convey my appreciation to Civil Engineering department especially the FYP Committees for conducting trainings and talks in enhancing our professional writing skills.

Finally, praise God for His gift of good family and friends who never stopped supporting me throughout the process of completing this project.

Thank you.

ABSTRACT

This paper presents results on literature and experimental works on Malaysia local sand for possible use as proppant specifically local sand resourced from Terengganu area. Proppant is a granular material that is mixed with fracturing fluid to hold fractures open after a hydraulic fracturing treatment is conducted in a formation. The oilfield developers in Malaysia obtain the supply of proppant from foreign suppliers as there is still no local proppant manufacturer and supplier in Malaysia. This is one of the causes of high well stimulation costs.

This project includes the study on the characteristics of proppants and research on the laboratory experiments in testing the characteristics of Terengganu sand as proppant. The sand sample from the desired area are tested by its; particle size distribution, density, roundness and sphericity, turbidity, mineralogy, crush resistance, permeability, and conductivity. The sand characteristics should meet the specifications set by American Petroleum Institute (API) or International Standard Organization (ISO) for commercial proppant.

The results obtained from the analyses are compared to the existing sand based proppant in the market. The size distribution, turbidity and bulk density of Terengganu sand agree with the commercial proppant. Even though Terengganu sand do not completely surpass the typical sand based proppant at certain characteristics (roundness, sphericity, crush resistance), they show promising results and meet some of the API and ISO requirements. Recommendations are also proposed in this paper for future improvement in increasing the quality of project results.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLES

ABBREVIATIONS

API	American Petroleum Institute
ISO	International Standardization Organization
JMG	Jabatan Geosains dan Mineral Malaysia
SEM	Scanning Electron Microscopy
UTP	Universiti Teknologi PETRONAS
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Well stimulation has been widely practiced to enhance petroleum reserves and daily production. It consists of two methods; hydraulic fracturing treatment and matrix treatment. Schlumberger oilfield glossary defines hydraulic fracturing as a stimulation treatment routinely performed on oil and gas wells in low-permeability reservoirs. Since Halliburton performed the first commercial fracturing treatment in 1949, over 1 million wells have been successfully fractured by the industry in the United States alone. (Halliburton, 2009).

Hydraulic fracturing is specially performed on reservoirs with low permeability to ease the flow of hydrocarbon into wellbore. Specially engineered fracturing fluid is pumped into the pay zone or desired fracturing area at rate and pressure high enough to extend and wedge the fracture hydraulically (Veatch, 1989). Propping agent such as grain of sand is added to the fracturing fluid to keep the fracture open and this propping agent is called proppant.

Proppant can be produced from naturally occurring sand, ceramic or bauxite which properties meet the American Petroleum Institute Recommended Practice (API RP) standards. Presently, there is still no local proppant manufacturer and supplier in Malaysia. Proppant is produced commercially from overseas, especially in the United States and Canada. These circumstances could lead to unsecured supply of proppant and instability of well stimulation cost.

Certain uncertainties will have to be overcome if the potential in producing our own local proppant manufacturer and supplier is to be looked upon as an alternative. This could be the strength resistance, the roundness and spherecity and other physical properties. In Malaysia, the abundant amount of natural silica sand is devoted to the country's glass-making and construction industry (Kwan, 2006).

1.2 Problem Statement

In the current oil and gas industry, oilfield developers in Malaysia are experiencing high cost of well stimulation with the minimum amount of USD 20 million (Rach, 2008). As hydraulic fracturing is widely practiced as one of the well stimulation methods, the demand on proppant is proportionally increased with the implementation of hydraulic fracturing. In certain situations, fracturing cost of a well may reach to 100% of the well drilling cost (Economides *et al.*, 1989). Therefore, a number of factors must be considered to optimize a particular treatment.

Up till today, there is still no local proppant producer and supplier, which leave the Malaysian oilfield developers with no other choice but to import proppant from foreign suppliers which contributes to the high cost of well stimulation. Therefore, an alternative of producing proppant locally could help reducing this problem. The abundant source of silica sand in Malaysia shows a potential for Malaysia to produce its own proppant. By introducing the application of Malaysian silica sand as proppant, it is also hoped that Malaysia economy would boost up with the progression of the sand industries and the reduced cost of well stimulation. Up till today, no prior studies have been done on the local silica sand for the use as proppant. This project will give an approach of the properties of local sand for the possible use as proppant.

1.3 Objective

The objective of this project is to investigate the potential of Malaysia to produce proppant locally by studying the characteristics of local sand so the cost of well stimulation in Malaysian oil fields can be reduced. In achieving the purpose of this project, these objectives are to be accomplished:

1.3.1 To characterize local sand for possible use as proppant

1.3.2 To identify various properties of proppant characterization based on American Petroleum Institute (API) standards.

1.3.3 To execute proppant tests on the selected local sand.

1.3.4 To compare the characteristics of local sand with the existing proppant in the market.

Besides reducing the cost of hydraulic fracturing in Malaysian oilfield, it is also our concern to exploit the natural source to develop the natural sand industry which until today has only been utilized for construction and glass-making industries. By introducing our abundant natural resource for application in the oil and gas industry, this can contribute to improvement in Malaysia economy especially if our proppant is qualified to be exported to the global market.

1.4 Scope of Study

This project would be initiated with knowledge gathering and theoretical studies. Case studies are read to have better understanding on the effect of proppant properties to well performance. Investigations on local silica sand distribution and reserves in Terengganu have been done through readings of reports prepared by Jabatan Mineral and Geosains Malaysia (JMG). Sample of silica sand from Terengganu are obtained from the source and certain laboratory experiments are planned to be carried out on the sand sample to determine the characteristics of the sand. The experiments include the analytic techniques involved in determining the sand properties which is recommended by the standards from API. The results obtained will be compared to the reference material. Conclusions are to be made from the tests and experiments conducted, and relevant recommendations are proposed to make the product of this project better.

CHAPTER 2

LITERATURE REVIEW and THEORY

2.1 Effect of Hydraulic Fracturing on Oil Production

SPE 77675 states that since 1973, there has been over 80 SPE papers documenting the production benefits achieved with higher conductivity fractures (CarboCeramics, 2009). The paper mentions on the success of hydraulic fracturing in increasing the oilfield productivity in over 35 geographic regions around the world. These production increases were documented by 250 authors, representing over 70 companies. SPE 77675 also states that higher conductivity fractures are found to be beneficial in oil, gas and condensate reservoirs. These benefits are shown in carbonates, sandstones and coals with well depth ranging from 100 to 20 000 feet. Fracturing can benefit in oil wells producing as little as 1 bopd and in gas wells producing less than 25 000 scf/d.

The effect of hydraulic fracturing on oil production can be observed from a case study on Kuparuk River Field, Alaska. As documented in three SPE papers (SPE 15507, 20707 and 24857), 880 frac jobs were performed by 1992 with 200 restimulation treatment conducted at Lower A sand lies at approximately 6000 ft TVD with permeability ranging from 20 to 100 md with the thickness of 30 ft pay. Figure 2.1 shows the production results specifically for a single Kuparuk Well 2F-08 after the stimulation treatment (CarboCeramics, 2009).

Initially, the formation was stimulated with 20/40 frac sand and performed an acceptable initial production rate of around 500 bopd. In 1987, the well was restimulated with more aggressive concentration of 20/40 sand increasing the oil rate to around 1000 bopd. In 1990, the introduction of 16/20 CarboLite increased the productivity of the well to over 3000 bopd. This high rate was not sustained due to the increasing of reservoir pressure and high production of gas in oil (CarboCeramics, 2009).

From the listed SPE papers, over 80 case studies have shown significant improvements in production rate and profitability can be achieved with increased fracture conductivity.

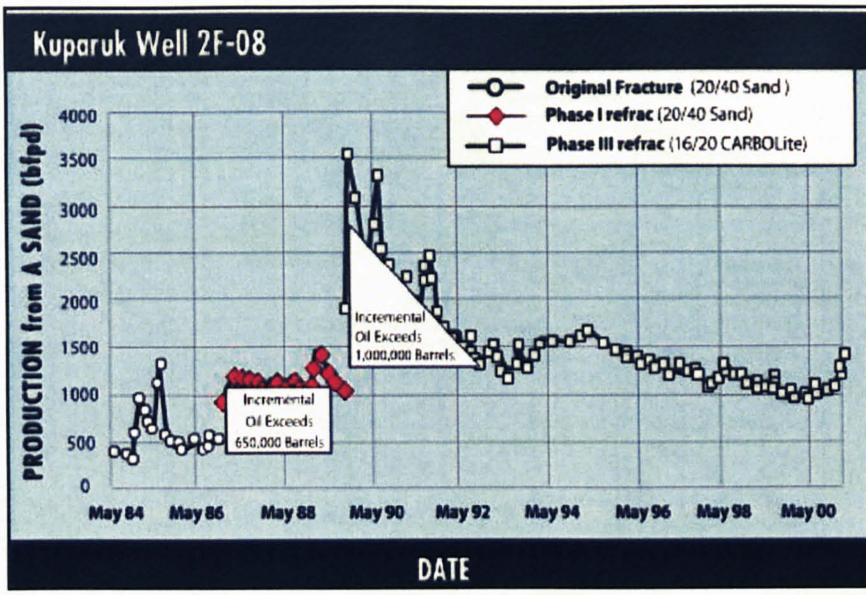


Figure 2.1. Production rate for Kuparuk Well 2F-08
(Source: CarboCeramic, 2009)

2.2 Proppant in Hydraulic Fracturing

Hydraulic fracturing is defined as a well stimulation technique designed to increase the productivity of a well by creating highly conductive fractures or channels in the producing formation surrounding the well (Lunghofer, 1985). Fracturing has made a significant contribution in enhancing oil and gas producing rates and recoverable reserves (Veatch *et al*, 1989). Figure 2.2 shows the typical fracturing process and the mechanisms involved.

A typical hydraulic fracturing process consists of two steps. First, a neat fluid called "pad" is pumped into the formation with very high pressure to initiate the fracture. This is followed by slurry of fluid mixed with propping agent called "proppant" which continues to extend the fracture and simultaneously transporting the proppant deeper into the fracture. From here, we understand that the functions of the fracturing fluid are to fracture the formation and transport the proppant deep into the fracture. After the materials are pumped, the fracturing fluid flows back out of well, leaving a highly conductive propped fractured for oil or gas to flow easily from the formation into the well (Veatch *et al.*, 1989).

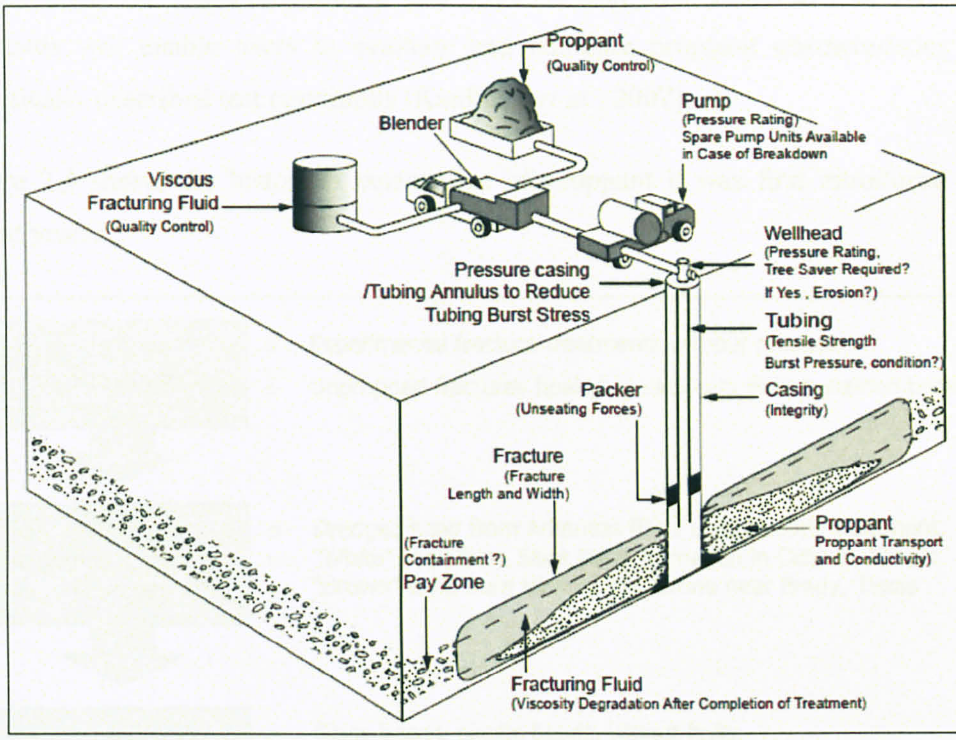


Figure 2.2. Practical issues during a propped hydraulic fracturing treatment
Source: Hydraulic Fracturing, Harriot-Watt University

Schlumberger (2009) oilfield glossary defines proppant as sized particles mixed with fracturing fluid to hold fractures open after a hydraulic fracturing treatment. The glossary also explains that proppant materials should be carefully sorted for size and sphericity to provide an efficient conduit for production of fluid from the reservoir to the wellbore. The objective of proppant fracturing is to pack the dynamic fracture with proppant so that when the fracture treatment has terminated and production commences, the fracture wil remain conductive (Schechter, 1992).

The American Petroleum Institute (API) has established sand quality specification in implementing it for fracturing treatment (Veatch *et al.*, 1989). These specifications cover size distribution, sphericity and roundness, solubility in acid, silt and clay content, and crush resistance. These properties will have to meet the standards by API Recommended Practice 56 (API RP 56) or the updated version of API RP 56, the International

Organization for Standardization's ISO 13503-2 and ISO 13505-5. The new ISO's standards will enable users to evaluate and compare proppant characteristics under specifically described test conditions (Kaufman *et al.*, 2007).

Figure 2.3 shows the historical perspective of proppant it was first introduced to the recent years.

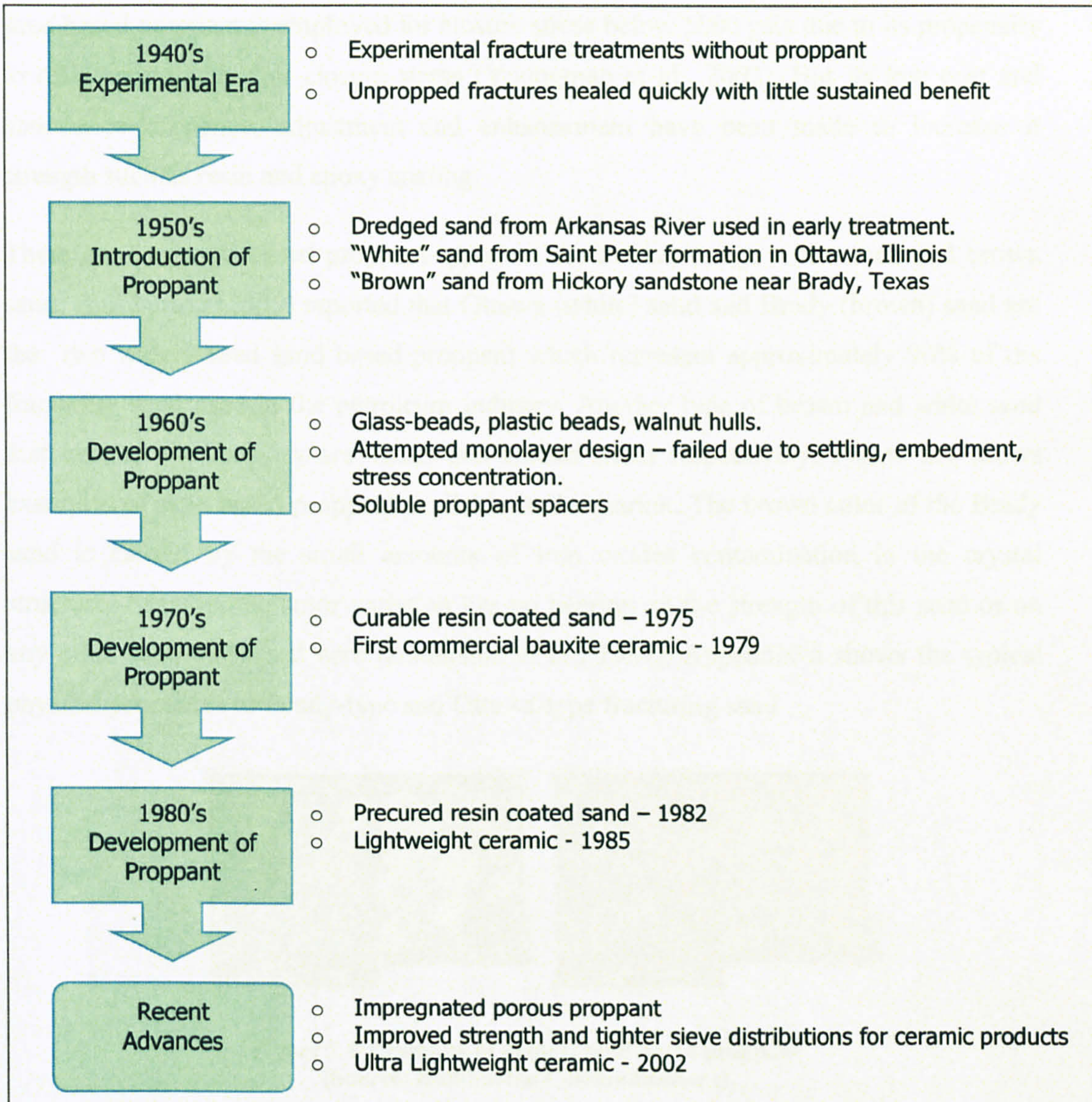


Figure 2.3. Historical Perspectives of Proppant
(Source: Data extracted from CarboCeramic, 2009)

2.3 Silica Sand Based Proppant

Silica sand is a term normally applied to high purity silica sand containing a high percentage of SiO_2 which is more than 98% (Eki and Johari, 2001). Silica sand is hard, chemically inert and has a high melting point, attributed to the strength of the bonds between the atoms. Currently, silica sand based proppant is the most commonly used proppant in the U.S due to its ready availability and low cost (Veatch *et al.*, 1989). Silica sand based proppant is employed for closure stress below 5000 psia due to its propensity to disintegrate at higher closure stress (Youngman et al., 2002). But its low cost and abundance existence, adjustment and enhancement have been made to increase it strength such as resin and epoxy coating.

There are two sand based proppant types on the market today, white sand and brown sand. Halliburton (2005) reported that Ottawa (white) sand and Brady (brown) sand are the two widely used sand based proppant which represent approximately 90% of the fracturing sand used in the petroleum industry. Another type of brown and white sand that used in the industry are Texas and Jordan sands respectively. Figure 2.4 shows examples of sand based proppant available in the market. The brown color of the Brady sand is caused by the small amounts of iron oxides contamination in the crystal structure. Even so, the color variation has no bearing on the strength of this sand or on any other sand discussed here (Anderson, *et al.*, 1989). Appendix 6 shows the typical physical properties of Brady-type and Ottawa-type fracturing sand.

Figure 2.4. Examples of natural sand based proppant (Source: Halliburton Communications)

2.4 Possibility of Producing Local Silica Sand based Proppant.

Many studies and reports have been done on the silica sand distribution in Malaysia by Malaysia Mineral and Geosciences Department (JMG) on various locations as early as dated back to 1976. These studies show that Malaysia has immense area of silica sand deposition with promising reserves volume. JMG has delineated an estimate of 148.5 million tones (Mt) of silica sand resources throughout the country. The largest of these are Sarawak, 45.7 Mt; Terengganu, 45.6 Mt; and Sabah, 29.9 Mt. Other states with silica resources are Selangor, 15 Mt; Perak, 10.8 Mt; Johor, 1.0 Mt; and Kelantan, 0.27 Mt (JMG, 2007).

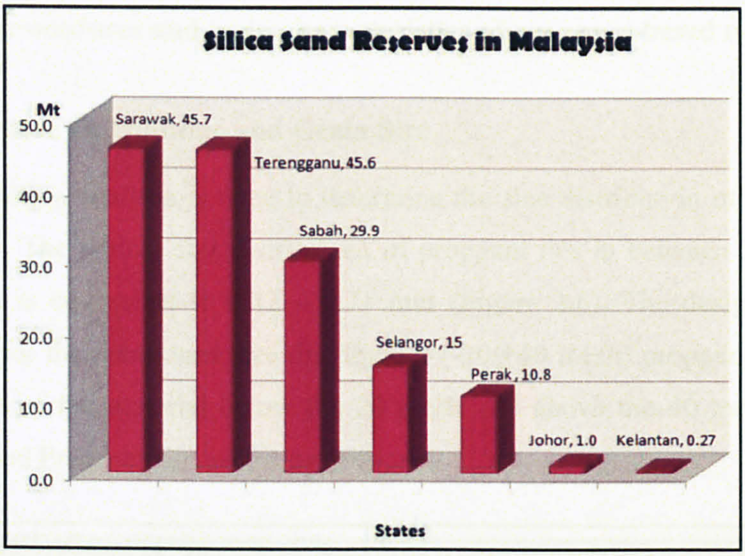


Figure 2.5. Silica Sand reserves distribution in Malaysia

Domestically, the bulk of silica sand produced goes towards the manufacturing of glass products with minor consumption by ceramics, foundries, glasswool production industry and for water treatment (JMG, 2007). Due to the abundant amount of silica sand in Malaysia, we have become one of the leading silica sand producers and exporters in the world. Appendix 2 shows the production of silica sand in Malaysia from 2005 to 2007 while Appendix 3 shows the summary of our silica sand external trade activity. This indicates that Malaysia has abundant resource of silica sand which shows promising future to produce local silica sand as proppant.

2.5 American Petroleum Institute Recommended Practice 56 and International Organization for Standardization (13503-2 and ISO 13505-5)

In 2001, a new committee was formed by the ISO and API to write procedures for measuring the properties of proppant used in hydraulic fracturing. As the result, a new document, ISO 13503-2 "Measurement of Properties of Proppant Used in Hydraulic Fracturing and Gravel -Packing" was written to replace API RP 56, 58 and 60. In 2003, a second committee came out with ISO 13503-5 "Procedures for Measuring the Long-Term Conductivity of Proppants" to replace API RP 61 (Kaufman *et al.*, 2007).

2.6 Testing procedures and main characteristics of proppant based on ISO 13503-2.

2.6.1 Sieve Distribution and Grain Size

Sieve distribution analysis is done to determine the size distribution of a particular sand sample. The typical size distribution of proppant lies in between 20 – 40 US Mesh which is equivalent to 0.42 – 0.71 mm (Figure 2.6). The designated sieve distribution for the mentioned size distribution (-20/+40 mesh) proppant must have at least 90% of the material below the 20 mesh and above the 40 mesh per API Recommended Practices for fracturing proppant.

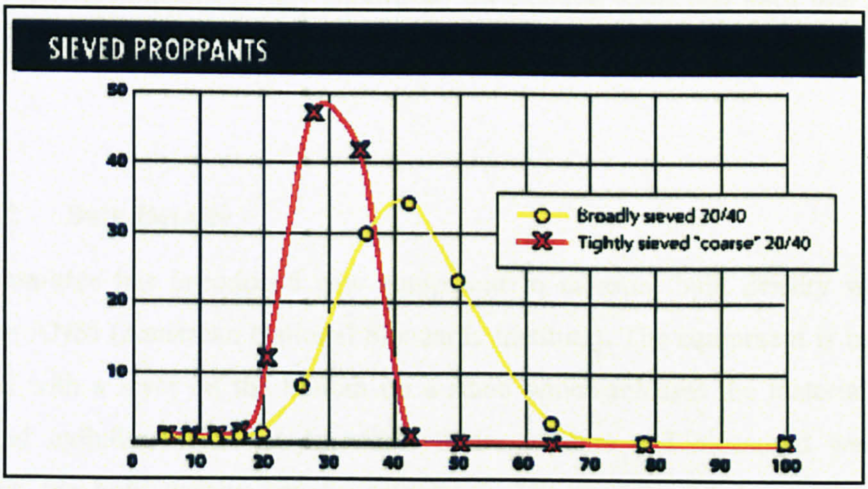


Figure 2.6. Particle Size Distribution
(Source: CarboCeramic, 2009)

Larger size proppant has greater individual strength comparing to the smaller ones. However, in high closure stress, the effect of large grain-sized proppant may deceive the permeability of formation due to low crush resistance on larger proppant. Figure 2.7 will give better explanation on this scenario.

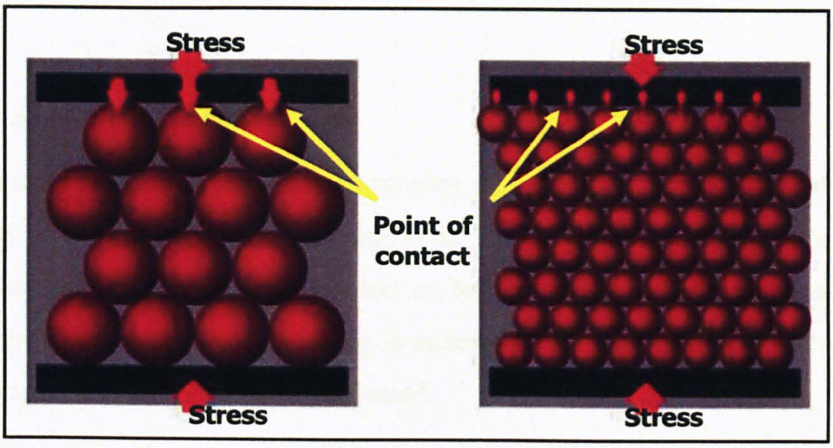


Figure 2.7. Closure Stress Distribution for Different Sizes of Proppant (Source: CarboCeramic, 2009)

Smaller grained proppant has the capability to distribute closure stress over greater number of contact points which means more uniformly. Due to its capability to distribute load to more contact points, smaller grain takes longer time to crush comparing to the larger grains, hence it has higher crush resistance. It is fair to say that large-sized proppant is only significant for shallow wells that have low closure stress. As the stress increases, smaller grain-sized proppant is more suitable.

2.6.2 Bulk Density

The committee has introduced new equipment to measure bulk density which is based on ANSI (American National Standards Institute). The equipment is basically a funnel with a lever on the bottom on a stand which releases the material into a calibrated cylinder. With the known cylinder volume and measured weight of proppant, the bulk density can be calculated. The recommended maximum bulk density for typical proppant is 105 lbm/ft^3.

It is important to determine the value of proppant bulk density since proppant are bought from the market by mass and not volume. Proppant that has lower density possesses more volume comparing to the proppant that has higher density of the same mass.

2.6.3 Crush Resistance Test

This test is conducted on sieved samples to determine the amount of proppant crushed at a given stress and is useful in determining and comparing the crush resistance of proppant. The evaluation on test results should give indication of the stress level where proppant crushing is excessive and the maximum stress to which the proppant material should be subjected.

Proppant have to withstand high closure stress to resist it from crushing and producing fines. The produced fines can decrease the permeability of fracture greatly once the porous medium between the sand particles is filled with fines. It is also understood that as reservoir pressure is reduced by fluid production, the closure stress will increase. Therefore, it is important that proppant strength be selected for the stress that will be present during the later life of the well.

2.6.4 Roundness and Sphericity

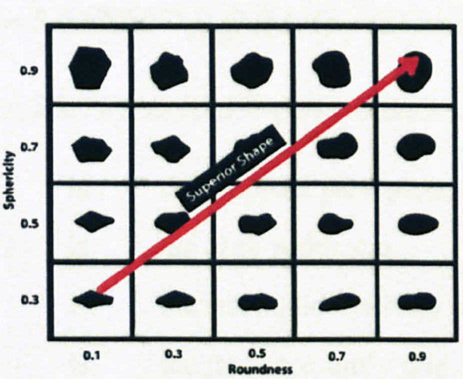


Figure 2.8. Krumbein Roundness and Sphericity Chart

Proppants are often described in term of roundness and sphericity (Kazi, 2007). **Roundness** is a measure of the relative sharpness of the grain corner while **sphericity** is the measure of how closely a particle to a shape of a sphere (CarboCeramic, 2009).

In the oil and gas industry, Krumbein Roundness and Sphericity Chart (Figure 2.8) is commonly used to determine the roundness and sphericity of proppant where higher value of Krumbein number indicates higher quality of proppant (CarboCeramic, 2009). The commercial sand based proppant possess the minimum value of 0.6 for both roundness and sphericity (Anderson *et al.*, 1989).

2.7 Testing procedures based on ISO 13503-5

ISO 13503-5 was established by the committee to guide users for a long term conductivity test procedures that has been missing in the oil and gas industry for decades (Kaufman *et al.*, 2007). The standard will give precise procedures for the test and description of the equipments. However, due to the lacking of standard equipment for proppant testing, the available equipments in the university are utilized in achieving the desired results.

According to ISO 13503-5, conductivity of proppant pack can be calculated using these equations;

$$kW_f = 5.41X10^{-4} \mu Q / (\Delta P) \quad \text{(SI units)}$$

$$kW_f = 26.78 \mu Q / (\Delta P) \quad \text{(US customary units)}$$

where	k	is	the proppant pack permeability md
	W_f	is	the pack width, cm
	μ	is	the test liquid viscosity at test temperature, cP
	Q	is	the flow rate, cm^3 / min
	ΔP	is	the pressure drop, kPa (psi)

Proppant pack conductivity is then defined as the multiplication of proppant pack permeability to the pack width, $\mathbf{kW_f}$.

2.8 Summary of Literature Review

Proppant is widely used in hydraulic fracturing; a well stimulation process means to increase the well production. Natural sand based proppant is still the world's largest demand due to its availability and low cost. Most of the frac sand in market is high-graded silica sand that passed the minimum requirements set by the API standards for examples in term of grain size, sphericity, roundness and crush resistance. In Malaysia, silica sand is deposited in several places in Peninsular Malaysia and Sarawak. Sarawak possesses the largest reserves of silica sand while Terengganu owns the second largest reserves. Sarawakian sand is being used for glass-making and construction industries. However the sand in Terengganu has not yet been exploited until today. So far, there is no local proppant supplier. Therefore, a final year project entitled "Characterization of Local Sand for Possible Use as Proppant" is conducted to study the potential of local sand as proppant. This project will give benefit, not only to oil and gas industry, but also to local silica sand industry by utilizing local minerals.

CHAPTER 3

METHODOLOGY

3.1 Project Flow

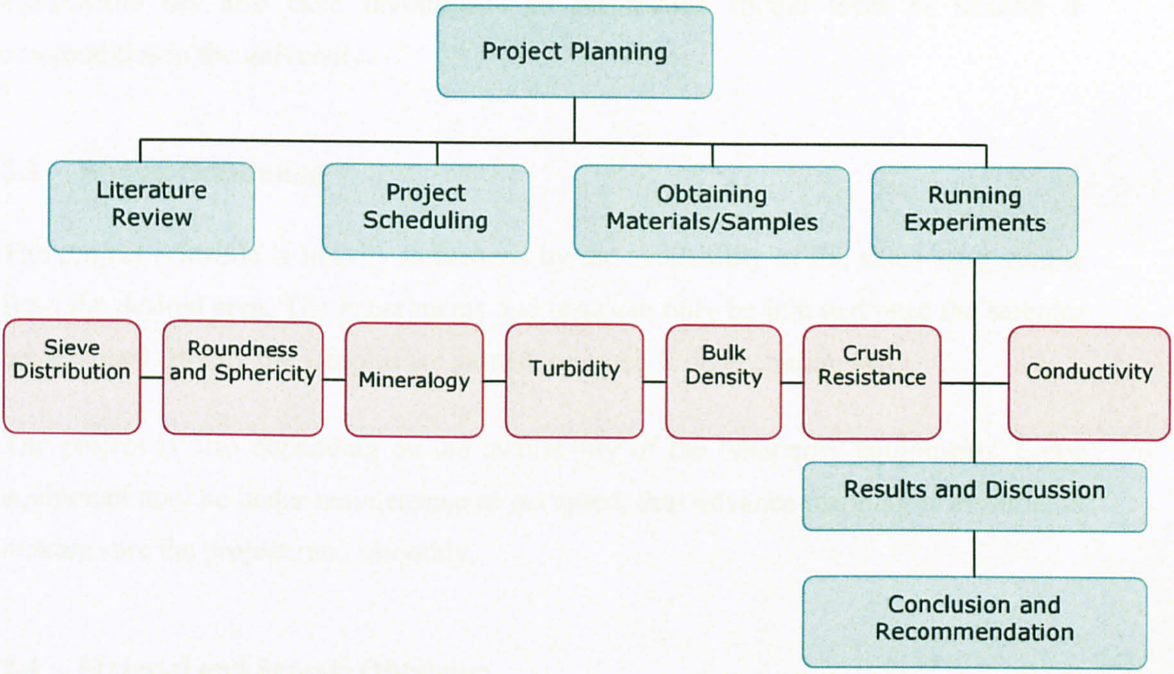


Figure 3.1.Project Flow

3.2 Literature Review

For this project, investigation and research are being approached from two angles; ISO and API procedures and minimum requirements for commercial proppant AND silica sand deposition in Malaysia and its characteristics. Thorough searches have been made through the internet (World Wide Web) and from the libraries to collect all available information on the above matter.

Visits have been paid to the public library of Malaysia Mineral and Geoscience Department (JMG) in Ipoh in order to obtain information on silica sand distribution and deposition in Malaysia, particularly in Sarawak and Terengganu. In gaining information on the standards of API and ISO, technical papers have been bought and subsidized by the university's Information Resource Centre (IRC) through the Society of Petroleum Engineers (SPE) web site. During this stage, the relevant experiments and tests have been identified in accordance to the latest standards of API and ISO. The availability of equipments has also been investigated as preparation should there be lacking in commodities in the university.

3.3 Project Scheduling

The project schedule is heavily influenced by the availability of the silica sand sample from the desired area. The experiments and tests can only be initiated once the samples are obtained. Before the samples are gained, research is done continuously.

The project is also depending on the availability of the laboratory equipments. Some equipment may be under maintenance or occupied, thus advance planning is essential in making sure the project runs smoothly.

3.4 Material and Sample Obtaining

Before any experiments and tests are held, it is essential for all material and equipment to be available. Enough samples should be obtained from the area of interest so tests can be conducted on them while comparing the samples properties to the properties of the commercial proppant. During the sampling, it is important to eliminate impurities by allowing 0.5 meter of overburden layer of the sand deposit as recommended by the reports from JMG.

3.5 Experiment and Testing

This stage is the most crucial phase in this project. Every experiments and tests are likely to be in accordance to the standards of API and ISO. The experiments which will be conducted are;

3.5.1 Sieve distribution analysis (BS812 : Part 103 : 1985)

This experiment is to determine the particle size distribution of sand particles

Figure 3.2. Sieve Shaker with Sieves

Equipment/Apparatus: Mechanical sieve shaker, drying oven, test sieves of different sizes (2.0mm, 1.18 mm, 0.60 mm, 0.425 mm, 0.3 mm, 0.212 mm and 0.15 mm), tray, sieve brush, electronic balances and scoop.

Procedures:

a. Sample is dried to a constant weight at a temperature of 110 +/- 5°C (230 +/- 9°F)
b. Suitable sieve sizes are selected to obtain the required information as specified.
c. The sieves are nested in order of decreasing size of opening from the top to bottom. The pan is placed below the bottom sieve. The sample is placed on top sieve. Lid is placed over top sieve.
d. The sieves are agitated by mechanical apparatus (sieve shaker) for 10 minutes.

e. The weight of material retained is determined on each sieve. The total weight should closely match the original weight of the sample. (within 0.3%)

f. The percentages of passing and total of percentages retained are calculated and sieve distribution graph is plotted

3.5.2 Bulk density test

These procedures are carried out to determine the bulk density of the sand.

Equipment/Apparatus: Balance and measuring cylinder.

Procedures:

a. An empty 100ml (100cc) measuring cylinder is placed on a weighing machine, and the reading of the machine is set to zero.

b. The measuring cylinder is filled with the sand sample until the reading is 100ml.

c. The reading is taken and bulk density is calculated from equation

$$\text{Bulk Density, } \rho = \frac{\text{weight of dry sand (g)}}{\text{Volume of dry sand (cc)}}$$

3.5.3 Roundness and Sphericity

This experiment is to determine the degree of roundness and sphericity of the samples.

Equipment/Apparatus: Scanning Electron Microscopy (SEM).

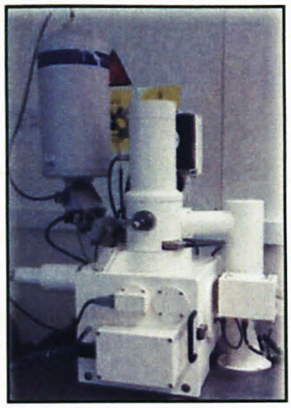


Figure 3.3. Scanning Electron Microscopy

The results from this experiment are then compared with the Krumbein Roundness Sphericity Chart (Appendix 4) to determine the degree of roundness and sphericity.

3.5.4 Turbidity test

This experiment is to determine the presence of suspended solid in the proppant

Figure 3.4. Turbidimeter

Equipment/Apparatus: Turbidimeter, turbidity cells with caps

Procedure:

a. 5g of sample is placed in the sample cell. The cell is filled with distilled water to the line (about 15 ml), taking care to handle the sample by the top. The cell is caped.
b. The cell is shook vigorously to suspend the particles present for 30 s +- 5 s.
c. The sample cell is placed in the turbidimeter and the turbidity readings are taken.

3.5.5 Mineralogy Analysis

3.5.5.1 X-Ray Fluorescence (XRF) : Elemental Analysis

This experiment is to determine the mineralogy of the sand samples.

Equipment/Apparatus: X-Ray Fluorescence, Enerpac Hand-Pressed Machine, and grinder.

Description: XRF is used for elemental analysis of many samples. XRF is non-destructive, multi-elemental, fast and economical if compare to other competitive techniques, such as Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Spectroscopy (ICPS) and Neutron Activation Analysis (NAA). The samples that are to be analyzed has to be compacted n pallet before the analysis can be conducted.

Figure 3.5. X-Ray Fluorescence Machine

3.5.5.2 X-ray Diffraction Analysis

This experiment is to trace the presence of silica dioxide, SiO_2 in the samples.

Equipment/Apparatus: X-ray Powder Diffraction (XRD) and grinder

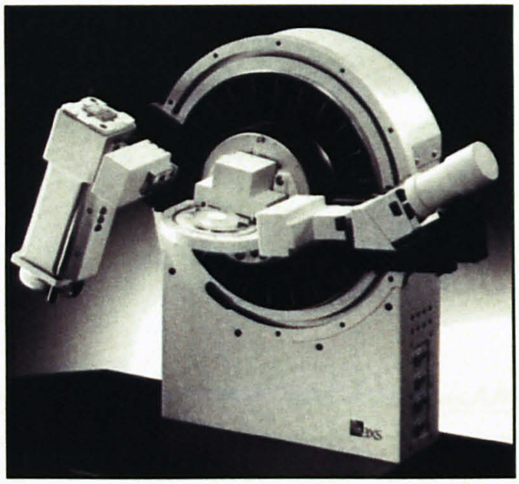


Figure 3.6. X-ray Diffraction Analysis (XRD)

Description: X-ray powder diffraction is a rapid analytical technique primarily used to phase identification of a crystalline material. For this project, it is used to confirm the XRF results.

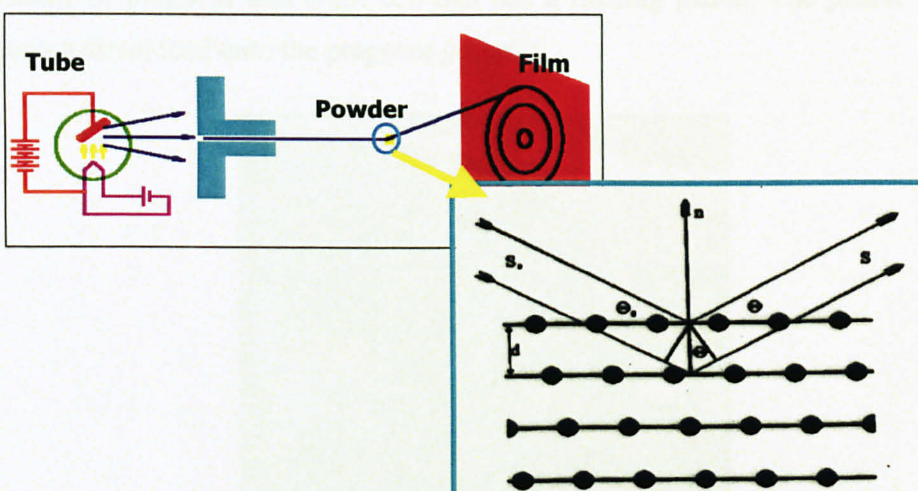


Figure 3.7. Methodology of XRD

From Figure 3.7, Bragg's formula is used to calculate the value of θ as every trace of element will give different value of θ

$$d = \frac{n \cdot \lambda}{2 \cdot \sin \theta}$$

And from this value of θ, Counts versus 2-theta-scale graph is plotted. (Figure 3.8)

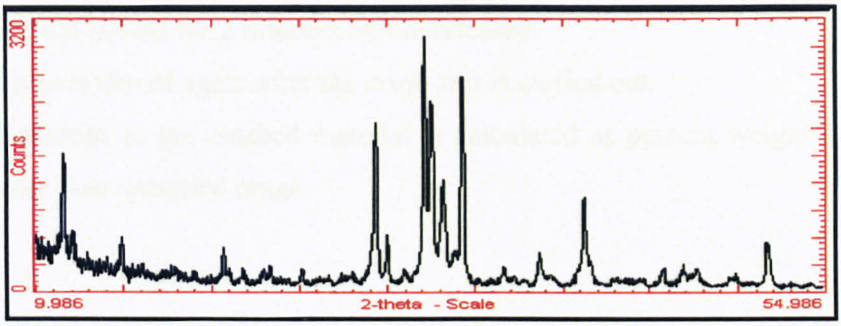


Figure 3.8. Counts versus 2-theta-Scale Graph

3.5.6 Crush resistance test

API procedures for measuring proppant crush resistance involve loading pre-set volume of proppant into crush cell that has a floating piston. The piston will then apply a direct load onto the proppant grains.

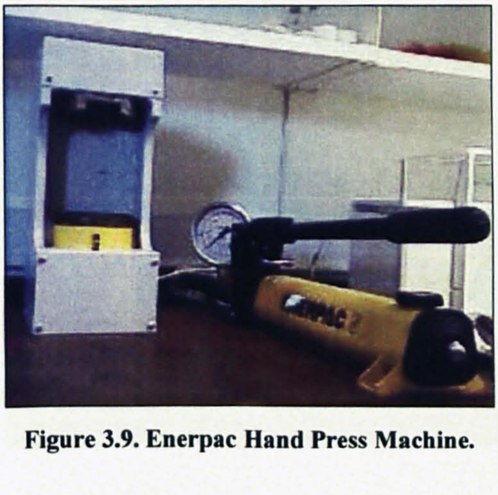


Figure 3.9. Enerpac Hand Press Machine.

Equipment/Apparatus: Enerpac Hand Press Machine, balance, crush cell.

Procedures:

a. The desired size of proppant particles is sieved.(e.g. -20/+40).
b. Crush cell is filled to a concentration of 1.95g/cm2 of sand.
c. A uniform loading rate is applied to the cell to reach the desired stress level (500 psi, 1000 psi, 1500 psi, 2000 psi and 2500 psi)
d. The stress is held for 2 minutes before released.
e. Material is sieved again after the crush test is carried out.
f. The amount of the crushed material is calculated as percent weight of proppant smaller than specified range.

3.5.7 Conductivity test (BPS-805)

The outcome of this experiment is to determine the permeability of proppant pack. From the value of permeability, conductivity can be calculated using the equation as discussed in the previous section.

Equipment/Apparatus: Bench Top Permeability System, brine solution 30 000 ppm, mould.

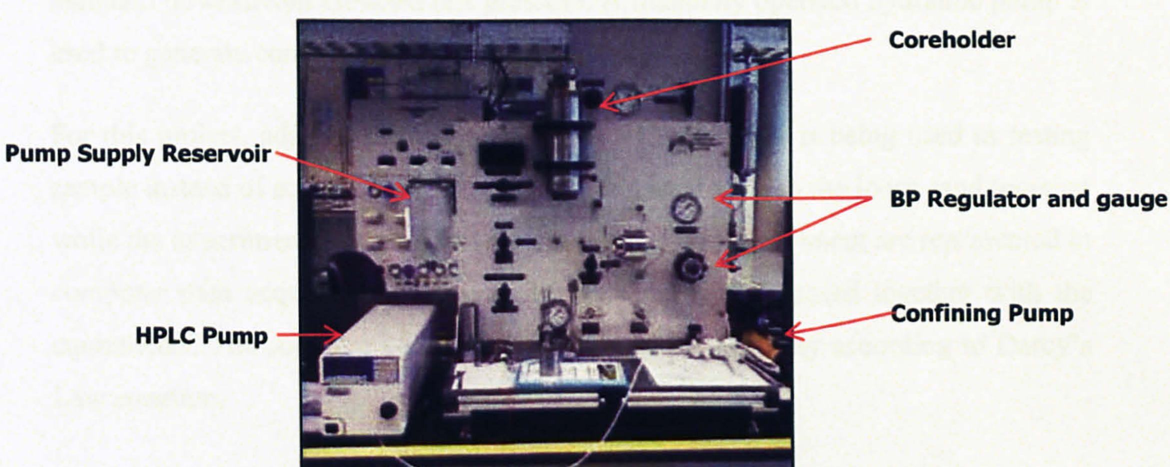


Figure 3.10. Bench Top Permeability System

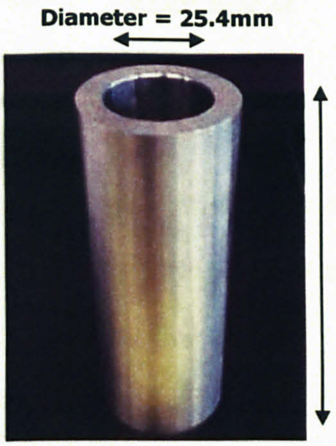


Figure 3.11. Mould

Description: BPS-805 is a manually operated system designed for performing simple liquid permeability tests at pore pressure to 5000 psi with confining pressure to 9950 psi. The standard system includes a low pulsation HPLC pump for fluid delivery at flow rates from 0.01 to 10 ml/min. This system is typically used for core samples which are held in a hassler core holder mounted vertically. The core holder can accommodate 1.5" diameter core samples one to four inches in length. A manual bypass valve is used to equilibrate pressure on the transducer preventing damage a high differential pressure. A dome-loaded backpressure regulator is utilized to maintain downstream elevated test pressure. A manually operated hydraulic pump is used to generate confining pressures to 9950 psi.

For this project, adjustments are being made as loose sand is being used as testing sample instead of compacted core log. Mould is used to keep the loose sand together while the experiment is carried out. The results for this experiment are represented in computer data acquisition system software which is purchased together with the equipments. The software computes the value of permeability according to Darcy's Law equation,

$$K = \frac{14700\,\mu\,Q\,L}{A\,\Delta P}$$

Where	k	is	permeability in millidarcies, md
	μ	is	viscosity of flowing fluid at test temperature, cp
	Q	is	liquid flowrate, cc/sec
	L	is	length of core sample, cm
	A	is	area of core sample, cm2
	ΔP	is	differential pressure across the core sample, psid
	14700	is	conversion factor from psi to atmosphere and from Darci to miliDarcies.

Test Liquid Preparation:

a) 30 gram of salt is measured and added to 1 litre of distilled water.

b) Solution is stirred until all the salt particle is completely dissolved in the distilled water.

Procedures:

a) Mould is installed into the core holder vertically.

b) Sand is filled into the core in three stages; for every stage manual compaction is carried out.

c) Core holder is closed tightly and all the inlet and outlet tubes are connected.

d) Test is run and the permeability value is observed from the software. The experiment is run long enough for the value of permeability to be constant.

Reminder:

a) Handling of bench top permeability system has to guided and supervised by laboratory technicians such as filling the confining system with hydraulic fluid, loading the core/sand sample in the core holder, unloading the sample from the core holder, transducer operation, pump operation, etc.

b) BPS-805 Operator Manual can be referred for more accurate procedure for each steps mentioned in (a).

CHAPTER 4

RESULT and DISCUSSION

4.1 Silica Sand Distribution and Deposition in Sarawak.

Research has been done heavily concentrated on the deposition and distribution of silica sand in the area of Miri and Bintulu, Sarawak (Figure 4.1). Sarawak became the first focus due to its largest silica sand reserve in Malaysia. Information from few reports was extracted from the library of JMG.

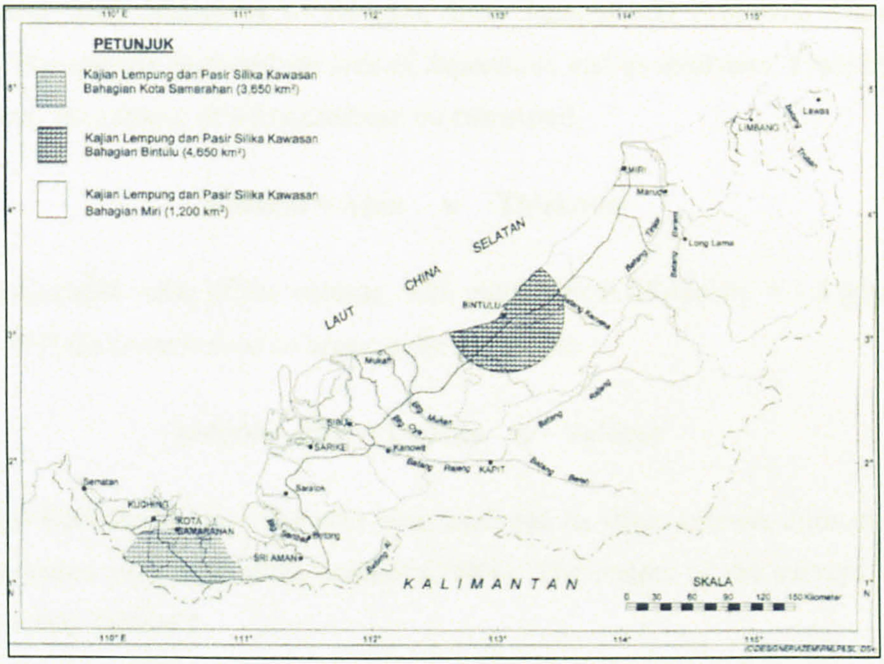


Figure 4.1.Areas of interest; Miri and Bintulu, Sarawak.

The silica sand in Sarawak contains high percentage of silica content (>98%). This indicates a good proppant property as silica content influences the strength of the sand. However, the average size distribution for Sarawakian silica sand ranges from 0.125 – 0.250 mm, which is much finer than the require particle size; 0. 41- 0.72 mm. Fine sand particles may have lower crush resistance hence decreasing the formation permeability. From the initial finding, the focus has been shifted to the silica sand in Terengganu.

4.2 Silica Sand Distribution and Deposition in Terengganu

Malaysia Mineral and Geosciences Department (JMG) reported that Terengganu possesses the largest reserves of silica sand in Peninsular Malaysia; 45.6 Mt. However, no silica sand is known to be exploited in Terengganu. In JMG's annual "Malaysian Mineral Yearbook", Terengganu has never been mentioned as one of the silica sand producers. This could mean that Terengganu's large reserves have not yet being disturbed and depleted.

Geological Survey Reports written by JMG are results from the surveying work of from five different areas in Terengganu; Kampung Rantau Abang 'B', West of Kampung Kuala Abang, Bukit semanyuk in Dungun, Batu Tampin and Kampung Meraga in Kemaman. The surveys included the area of deposition, and its thickness. From the area and thickness, the volume of silica sand can be calculated.

Volume = Area x Thickness

From the calculated value of the volume, with employment of density = 1.8 g/m^3 , the total silica in place (reserves) of an area can be computed.

Reserves (Mt) = Density x Volume

The samples from the surveys had also been analyzed its silica content. Almost all the samples indicated very high silica content (>99%). The results of the surveys can be summarized into Table 4.1

As mentioned earlier, most of the produced silica sand in Malaysia is being consumed by the glassmaking industry. The writer of the survey reports, P.C Aw however claimed that glassmaking do not require silica sand of such high grade. In addition, in his report written in the year 1978, he even suggested that the possibility of silica sand in Terengganu to be used as fracturing sand for hydraulic fracturing (Appendix 5). Based on these supportive tenets, it has been decided that to proceed this project with the focus on the silica sand of Terengganu.

Table 4.1. Summary the Deposition of Silica Sand in Terengganu and its Properties.

Location	Area (acres)	Average Thickness (m)	Reserves (mt)	Size (mm)	SiO_2 content (%)
Kampung Rantau Abang 'B'	356	1.5	2.16	0.3 -0.6	99.62
West of Kampung Kuala Abang	101.3	1	0.738	0.3 - 0.6	99.73
Bukit semanyuk, Dungun	109	1	1.14	0.3 - 0.6	99.70
Batu Tampin, Kemaman	12	1.3	0.1117	0.177 – 0.6	98.51
Kampung Meraga, Kemaman	20.5	1.5	0.208	0.3 – 0.6	99.62

4.3 Material and Sample Obtaining

Figure 4.2. Sign Board of Kampung Meraga

Figure 4.3. Sample is taken beneath the 0.5 m of overburden layer

Silica sand sample has been obtained from two of the five studied areas in Terengganu; Kampung Batu Tampin and Kampung Meraga. The sampling was carried out in August 2009. The areas of interest are identified from the details and directions recorded in reports obtained from JMG in the previous part of the project. Commercial proppant which is available in the market has also been obtained so physical comparison of local sand and commercially available proppant can be observed. Be noted that starting from this point, commercial proppant will be referred as **Sample 1**, Kampung Meraga sand as **Sample 2** and Batu Tampin sand as **Sample 3**.

4.4 Experimental Results

4.4.1 Sieve Analysis

Sieve analysis has been done on the second sample of the sand from Kampung Meraga and Batu Tampin as soon as the samples were brought back to UTP. And the results for both sand samples are shown as in Table 4.2 and 4.3 and Figure 4.4.

Table 4.2. Particle Size Distribution for Kampung Meraga

Sieve Size (mm)	Weight of Sieve (g)	Weight of sieve + sand (g)	Weight retained (g)	Percentage retained (%)	Total Passing (%)
1.180	354.63	379.81	25.18	1.26	1.26
0.600	329.94	730.67	400.73	20.04	21.30
0.425	282.00	1289.98	1007.98	50.40	71.69
0.300	280.00	703.89	423.89	21.19	92.89
0.212	346.04	474.19	128.15	6.41	99.30
0.150	333.47	345.92	12.45	0.62	99.92
0.063	261.75	263.04	1.29	0.06	99.98
Pan	389.26	389.59	0.33	0.02	100.00

Table 4.3. Particle Size Distribution for Batu Tampin

Sieve Size (mm)	Weight of Sieve (g)	Weight of sieve + sand (g)	Weight retained (g)	Percentage retained (%)	Total Passing (%)
1.180	354.63	413.45	58.82	2.94	2.94
0.600	329.94	915.27	585.33	29.27	32.21
0.425	282.00	1335.15	1053.15	52.66	84.87
0.300	280.00	537.00	257.00	12.85	97.72
0.212	346.04	387.19	41.15	2.06	99.77
0.150	333.47	336.93	3.46	0.17	99.95
0.063	261.75	263.40	1.65	0.08	100.03
Pan	389.26	389.70	0.44	0.02	100.05

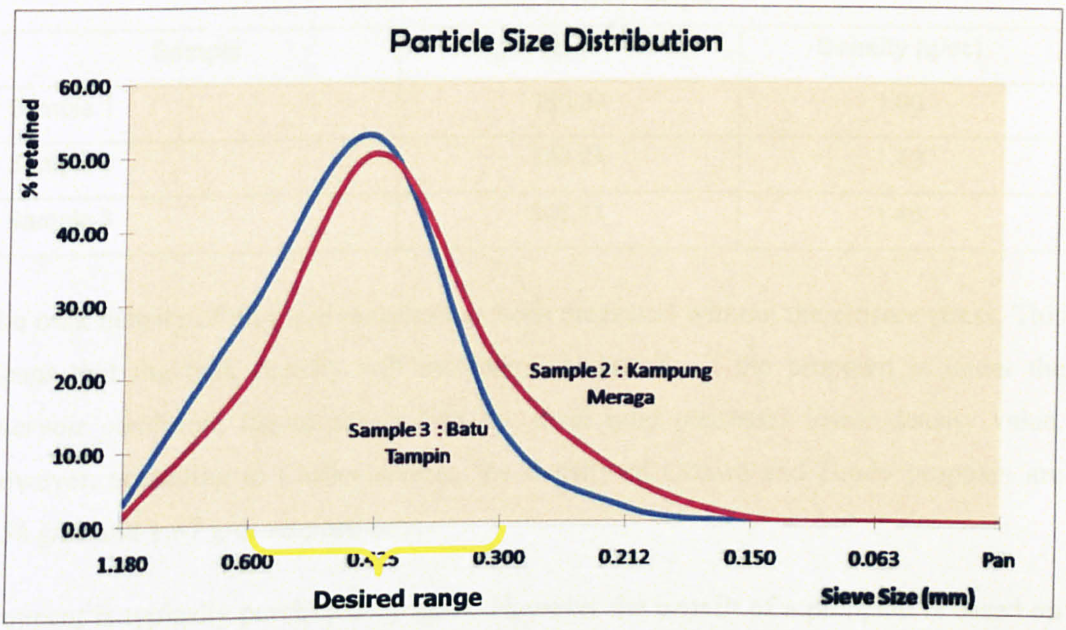


Figure 4.4. Size Particle Distribution for Kampung Meraga and Kampung Batu Tampin.

The sieve analysis results indicate that the particle size distribution from both Kampung Meraga and Kampung Batu Tampin agree with the report written by JMG. More than 70% of the sand particle is in the range of 0.3 – 0.6mm. But most importantly, the results show that the sand is in the range of the desired particle size of 0.41 – 0.72 mm. The graphs show that the sand is not tightly distributed, which means that they are not greatly uniform. This could due to the sampling method. More volume from scattered area should be taken from one location to achieve better sample representation.

4.4.2 Bulk Density

Table 4.4 shows the bulk density for each sand samples. Bulk density describes mass of sand particles that fills a unit volume, and includes both sand and porosity void volume (CarboCeramics, 2008).

Table 4.4. Density of Sand Sample

Sample	Weight (g) for 100cc	Density (g/cc)
Sample 1	160.34	1.60
Sample 2	149.24	1.49
Sample 3	146.71	1.46

The bulk density of all three samples has been measured without the closure stress. This means that the bulk density will increase substantially if the proppant is under the reservoir condition. Result shows that the local sand possesses lower density value. However, according to CarboCeramic, the density of Ottawa and Brady proppant are 1.54 g/cc and 1.57 g/cc respectively.

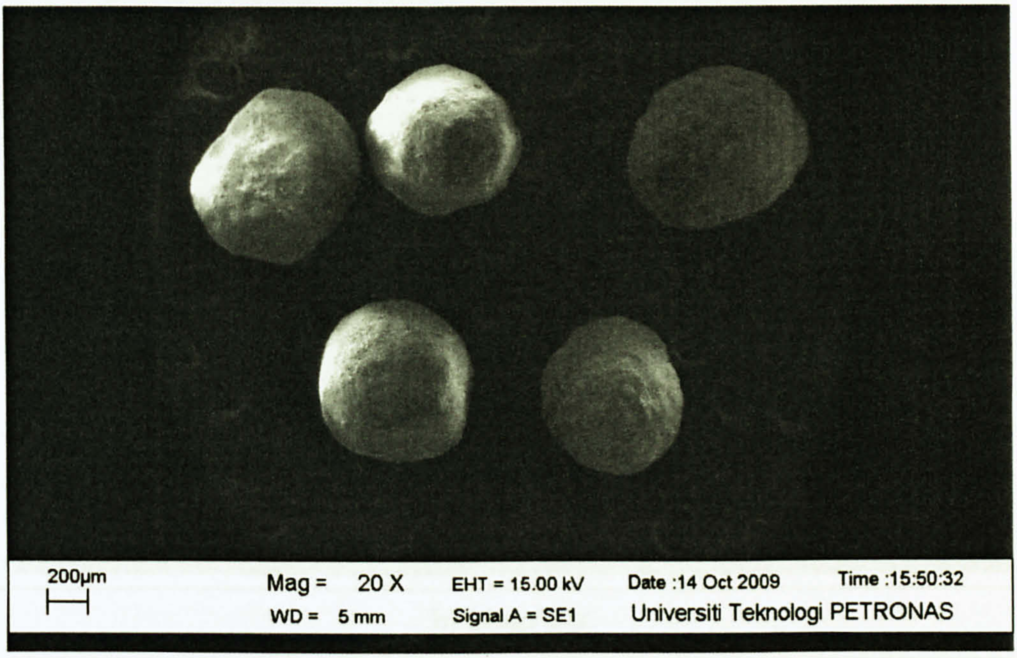
Proppant is typically purchased by mass. However the benefit of a proppant is based on its volume. For example, a fracture containing 100 000 pounds of local sand will occupy more volume than a fracture containing 100 000 pounds of Ottawa sand. For typical hydraulic fracturing, the density of the proppant will significantly impact the achieved fracture width (CarboCeramics, 2008). Fracture width will be narrower with denser proppant.

4.4.3 Scanning Electron Microscopy (SEM) Analysis

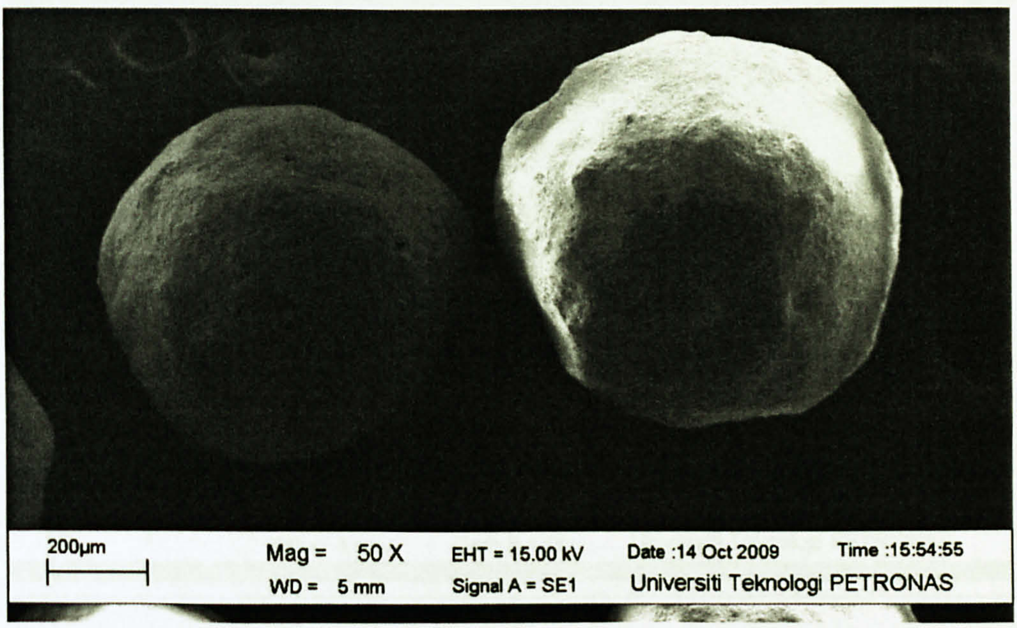
Table 4.5. Photomicrograph

Sample 1. Commercially Available Proppant

a) Mag: 20x

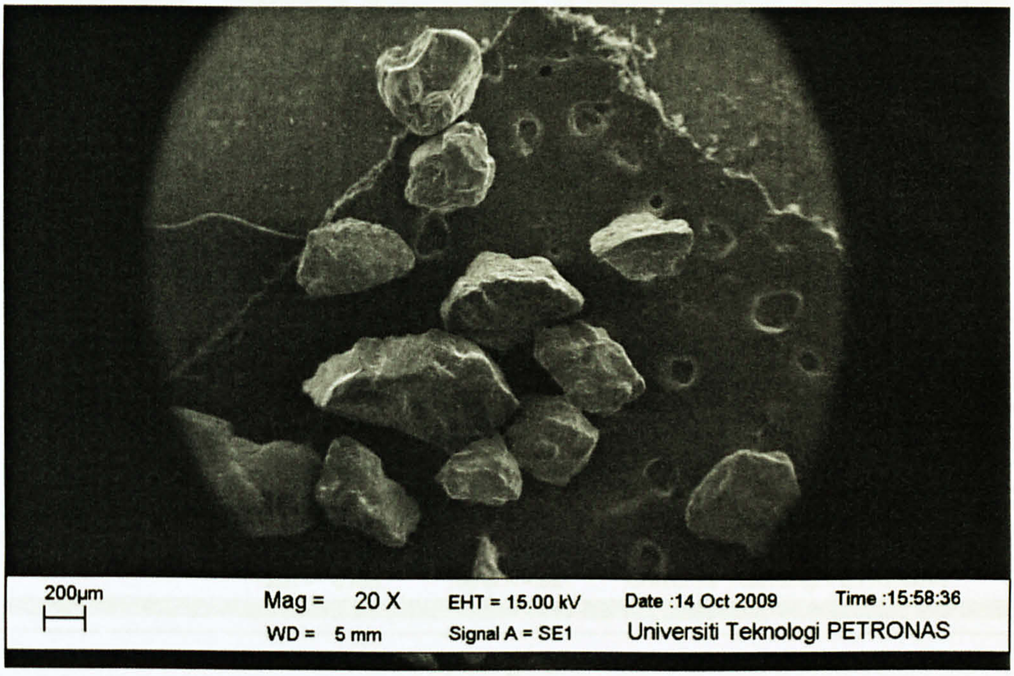


b) Mag: 40x

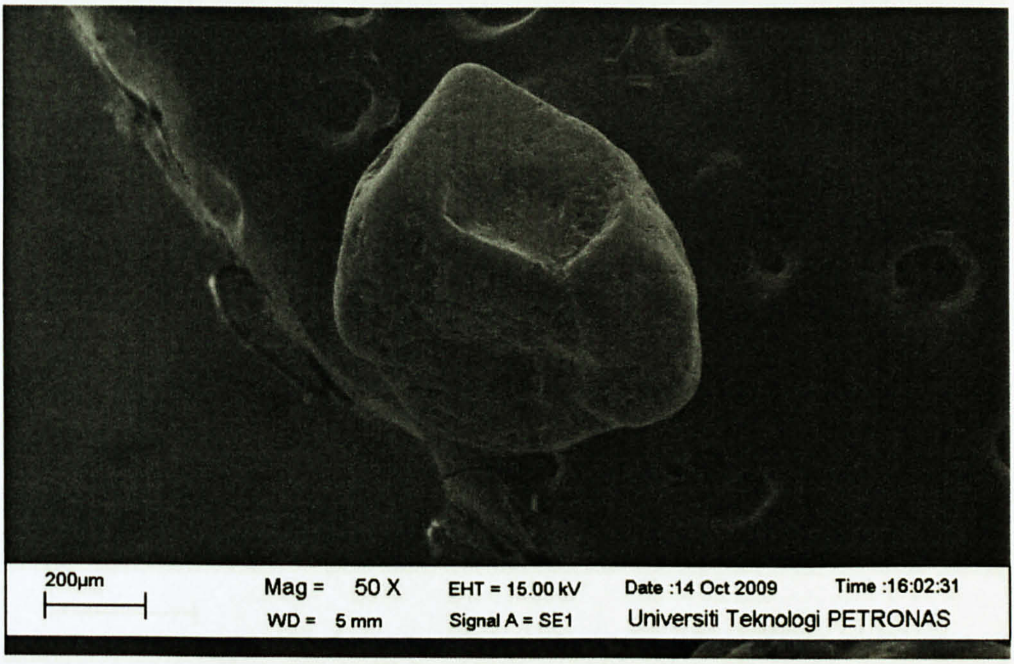


Sample 2. Kampung Meraga Sand

a) Mag: 20x

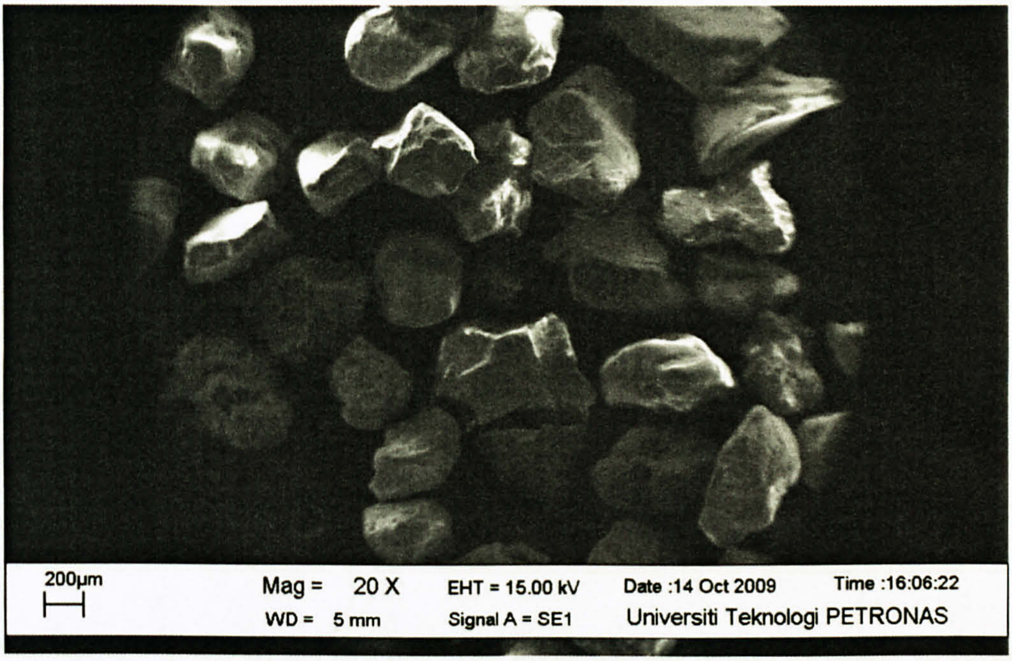


b) Mag: 40x



Sample 3. Kampung Batu Tamping Sand

a) Mag: 20x



b) Mag: 40x

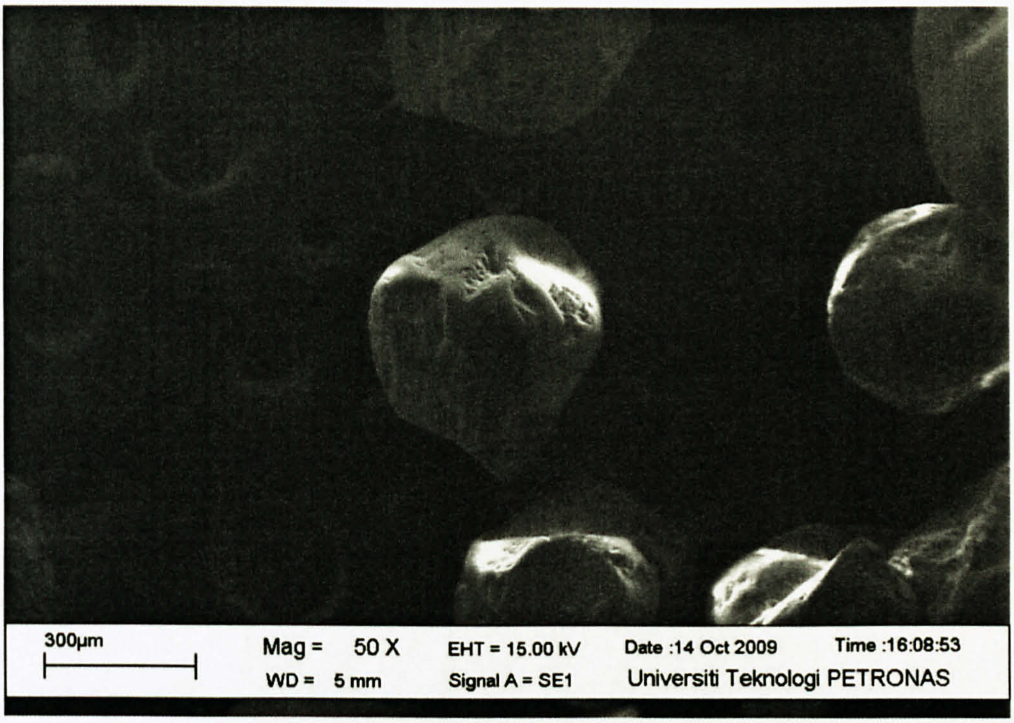


Table 4.5 shows the photomicrograph of the sand samples using Scanning Electron Micrograph (SEM) with magnifying of 20x and 40x. Sphericity and roundness of these samples are to be determined with the help of Krumbein Roundness and Sphericity Chart. From *Journal of Sedimentary Petrology* by W. Krumbein, Krumbein Chart is a comparative chart where no mathematical formula is employed in obtaining the value of roundness and sphericity. Table 4.6 explains the comparison results of the sand sample to the Krumbein Chart.

Table 4.6. Roundness and Sphericity of Samples

Samples	Roundness	Sphericity
Sample 1	0.7	0.9
Sample 2	0.5	0.7
Sample 3	0.5	0.7

Roundness and sphericity are two important properties due to their influence on porosity of the proppant pack once it is being injected into the formation. Typical sand proppant should possess the value of 0.7 for both roundness and sphericity. As shown in Table 4.6, commercial proppant meets the requirement for desired roundness and has ideal value for sphericity. This gives good indication of its good conductivity. The local sand samples however do not meet the desired value. The roundness and sphericity of our local sand do not transgress greatly comparing to the required value. Some adjustment could be looked upon in mending this drawback.

Roundness and sphericity of Ottawa and Brady sand can be obtained in Appendix 6.

4.4.4 Turbidity Test

After shaking the turbidity cells vigorously for all three samples, the turbidity values that are obtained from turbidimeter are shown in Table 4.7.

Table 4.7. Turbidity of Sample 1, Sample 2 and Sample 3

Sample	Turbidity (FTU)
Sample 1	226
Sample 2	232
Sample 3	241

Ottawa and Brady sand has the maximum turbidity value of 250 FTU. All three samples meet the requirement that is set by the industry for turbidity.

4.4.5 Mineralogy Analysis

4.4.5.1 XRF Analysis

Table 4.8. Chemical composition of Sand Sample

Content (Weight %)	Sample 1	Sample 2	Sample 3
SiO_2	**46.07**	**88.94**	**88.18**
Al_2O_3	49.46	5.30	5.73
K_2O	0.0948	1.47	1.14
Cr_2O_3	0.0127	Nil	Nil
Fe_2O_3	1.053	0.8379	1.034
ZrO_2	0.06639	0.0043	Nil
CaO	0.181	1.43	1.50
MgO	Nil	0.905	1.18
TiO_2	2.237	0.144	0.204
MnO	Nil	0.009	0.010
Rb_2O	Nil	0.0040	Nil
P_2O_5	0.776	0.958	1.01
V_2O_5	0.0317	Nil	Nil
Ga_2O_3	0.0091	Nil	Nil
SrO	nil	0.0061	0.0066

Sample 2 and 3 show high content of silica which indicates good purity of silica sand. Sample 1 however shows high percentage of Al_2O_3. Al_2O_3 is an additive that has been added to Sample 1 (commercial proppant) to increase its strength. More information on this additive is discussed in the results of the next mineralogy analysis, XRD.

The surveying report from Jabatan Mineral dan Geosains Malaysia has provided us with the initial study on the chemical composition possessed by Sample 2 and 3.

Table 4.9. Chemical Composition for Sample 2 and 3 (JMG Report)

Composition	Mean (%)	
	Sample 2	Sample 3
SiO_2	99.16	98.51
Fe_2O_3	0.037	0.044
TiO_2	0.54	1.27
Al_2O_3	0.029	0.030
CaO	-	-
Mgo	-	-
L.O.I	0.22	0.16

As observed, the value of SiO_2 as recorded in the report is much higher than the value measured from XRF machine. Bear in mind that the report obtained by JMG was written 20 years ago in 1989. The sand obtained from the site may have been weathered so it is recommended that future sampling to be conducted with the consideration of deeper overburden layer to eliminate the weathered and contaminated sand layer.

4.4.5.2 XRD Analysis

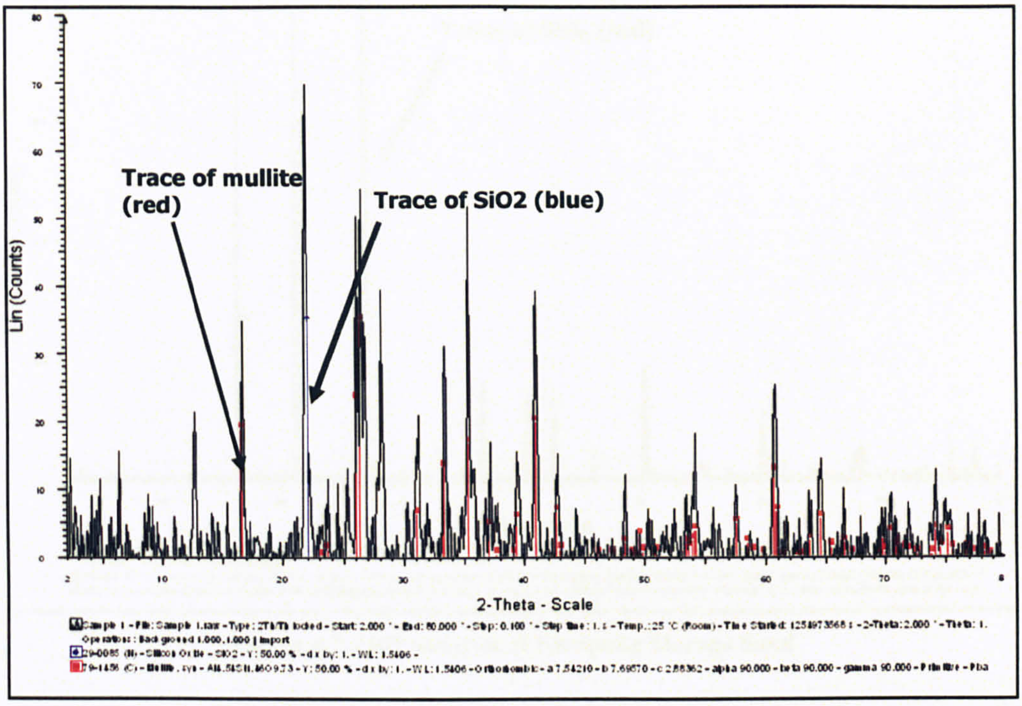


Figure 4.5. XRD Analysis of Comercial Proppant

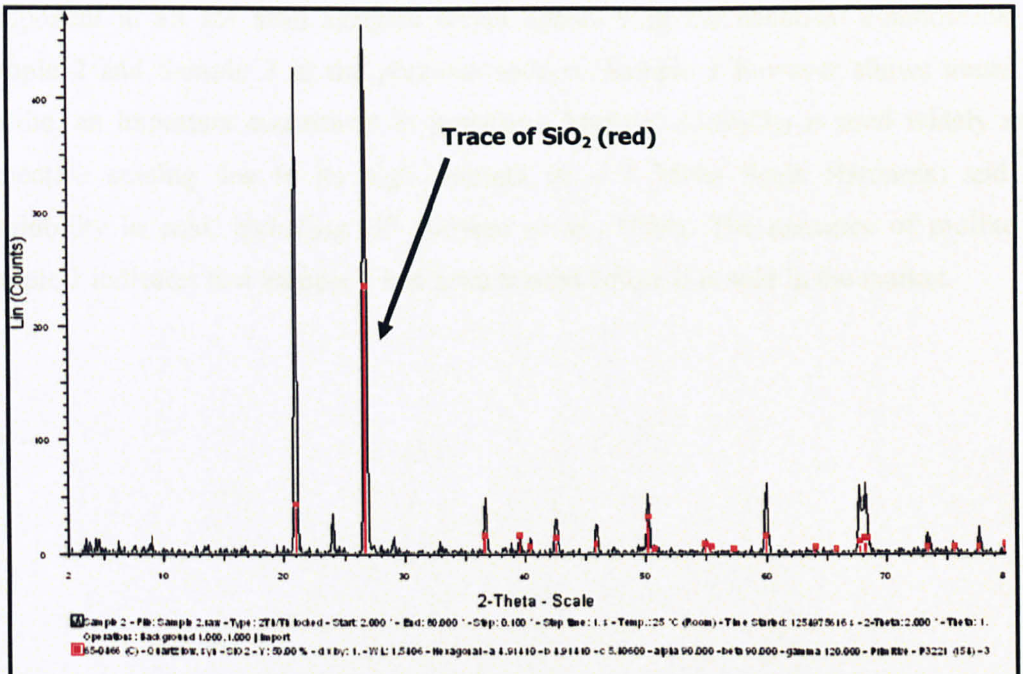


Figure 4.6. XRD Analysis of Kampung Meraga Sand

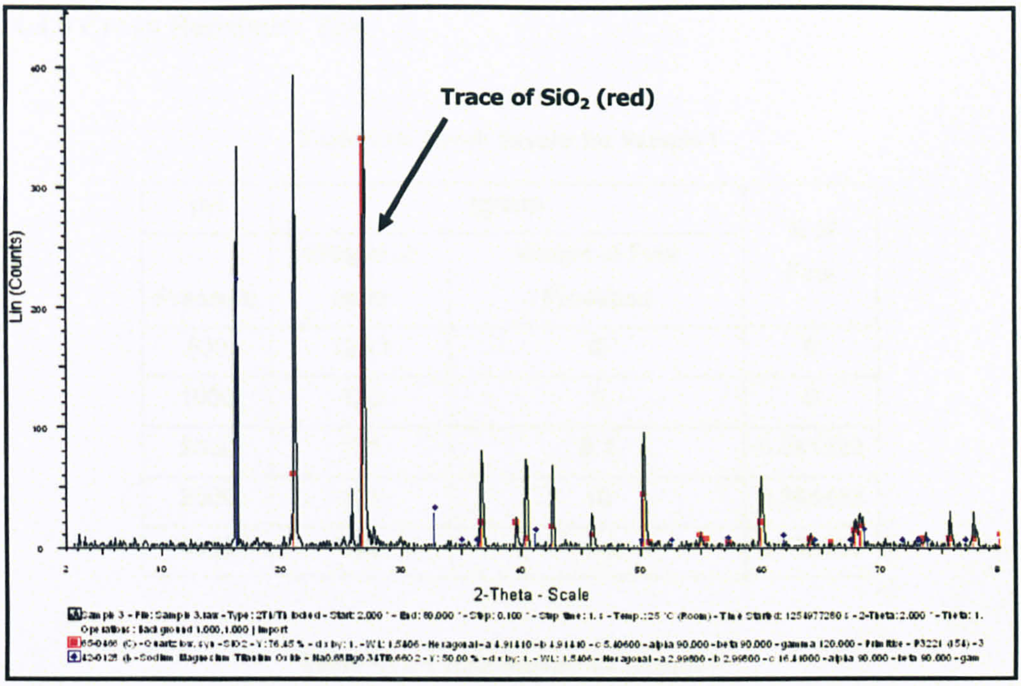


Figure 4.7.XRD Analysis of Kampung Meraga Sand

Based on the XRD results in Figure 4.5, Figure 4.6 and Figure 4.7, SiO_2 is the dominant component in all the sand samples which agrees with the chemical composition of Sample 2 and Sample 3 in the previous section. Sample 1 however shows traces of mullite, an important constituent in porcelain. Mullite, $Al_6Si_2O_{13}$ is used widely as a protective coating due to its high strength (6 – 7 Mohs Scale Hardness) and its insolubility in acid, including HF (Bowen *at al.*, 1924). The presence of mullite in Sample 1 indicates that Sample 1 had been treated before it is sold in the market.

4.4.6 Crush Resistance Test

Table 4.10. Crush Results for Sample 1

psi	(gram)		% of Fine
Pressure	Weight of sand	Weight of Fine Produced	
500	120.1	0	0
1000	120	0	0
2000	121	6.1	5.041322
2500	121	10	8.264463
3000	120	14.2	11.83333

Table 4.11. Crush Results for Sample 2

psi	(gram)		% of Fine
Pressure	Weight of sand	Weight of Fine Produced	
500	120	3.9	3.25
1000	120	11.9	9.916667
1500	121.3	20.4	16.81781
2000	122.2	25	20.45827
2500	121	28.7	23.71901

Table 4.12. Crush Results for Sample 3

psi	(gram)		% of Fine
Pressure	Weight of sand	Weight of Fine Produced	
500	120.2	2.3	1.913478
1000	120	11.8	9.833333
1500	120.2	18.6	15.47421
2000	120	23.8	19.83333
2500	120	28.6	23.83333

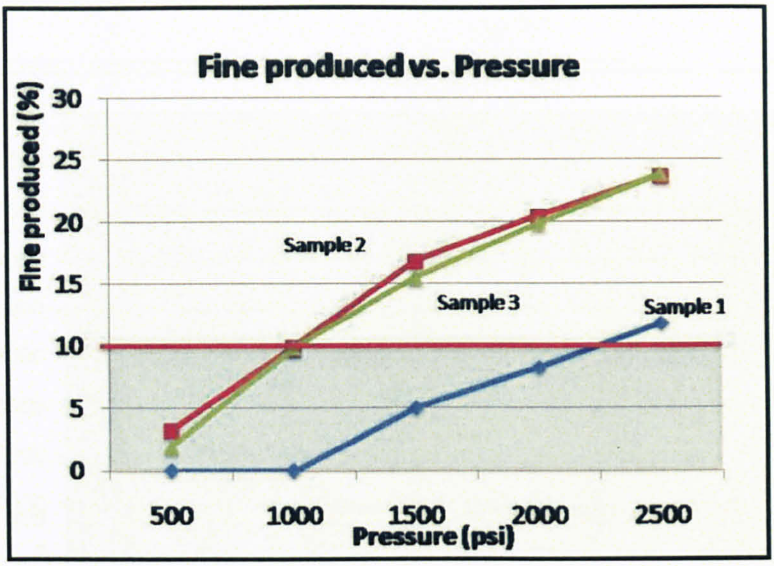


Figure 4.8. Crush Resistance Comparative Graph

API standard only allows 10% by weight of fine production after pressure is exerted on it. Results in Table 4.10, Table 4.11, and Table 4.12 can be best presented in Figure 4.8. Sample 1 shows really high crush resistance comparing to Sample 2 and 3 where it does not produce 10% of fine by weight until 2250 psi confined pressure. Meanwhile, Sample 2 and Sample 3 start to produce more than 10% of fine by weight as the confined pressure reaches 1000 psi.

As mentioned previously, particle shape influences the crush resistance of the sand. Angular grains tend to crush easier comparing to rounder ones. Roundness of Sample 1 is superior to Sample 2 and 3 hence it possesses higher crush resistance. Rounder particles have more consistence contact point where load then are uniformly distributed internally.

4.4.7 Conductivity Test

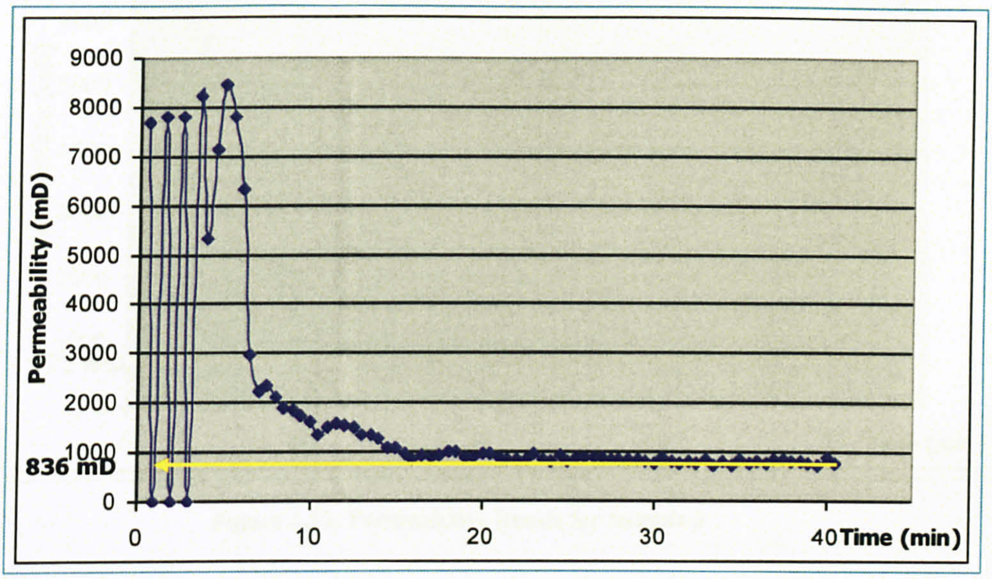


Figure 4.9. Permeability Result on Sample 1

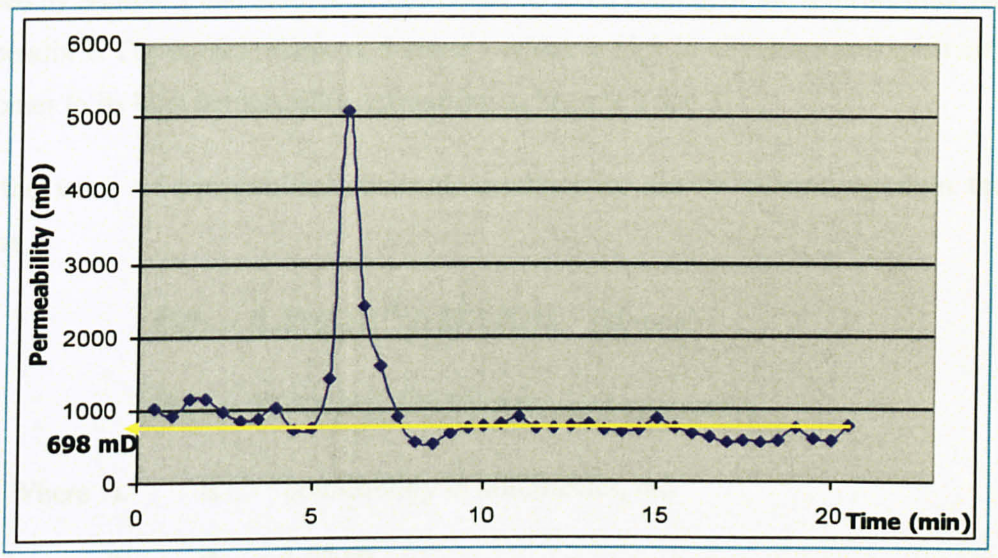


Figure 4.10. Permeability Result on Sample 2

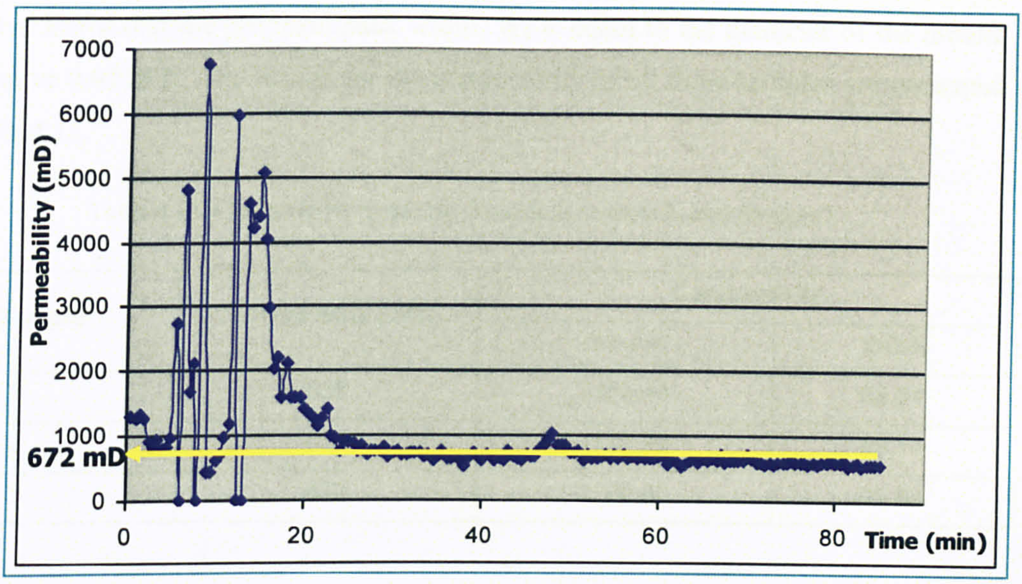


Figure 4.11. Permeability Result for Sample 3

The permeability value shown on each graph is the averaged value from the constant line. The results show that Sample 1 possesses the highest value of permeability, followed by Sample 2 and Sample 3. The tables for each reading of the tests are attached in Appendix 7. The particle shape of Sample 1 which is high in roundness and sphericity contributes to its high permeability, comparing to Sample 2 and 3.

From the value of permeability obtained, conductivity can be determined from the equation,

$$kW_f = 5.41X10^{-4}\,\mu\,Q/(\Delta P) \quad \text{(SI units)}$$

$$kW_f = 26.78\,\mu\,Q/(\Delta P) \quad \text{(US customary units)}$$

Where	k	is	permeability in millidarcies, md
	μ	is	1.05 cp
	Q	is	1.50 cc/sec
	L	is	5.08 cm
	A	is	5.06 cm^2
	ΔP	is	a variation from 0.1 psi to 0.5 psi

We have learnt that the proppant pack width, W_f is equal to the diameter of the mould, **2.54 cm** or **0.0833 ft**. The results for the conductivity of all three samples are presented in Table 4.13.

Table 4.13. Conductivity Value for Sample 1, Sample 2, and Sample 3

Sample	Permeability (mD)	Conductivity	
		mD.cm	mD.ft
Sample 1	836	2123.44	69.64
Sample 2	698	1772.92	58.14
Sample 3	672	1706.88	55.98

As expected, Sample 1 gives the highest value of conductivity comparing to Sample 2 and Sample 3. Be reminded that the equipment utilized for this particular conductivity test is not the standard equipment for proppant testing. Various confined pressure should be exerted onto the sand samples in representing the formation pressure. Due to the presence of the mould that holds the loose sand in the core holder, the sand sample is "protected" from the applied confined pressure. For this reason, the dependency on the accuracy of the results is still questionable. However, the outcome of this experiment should give good initial indication on the qualitative assessment on the samples.

CHAPTER 5

CONCLUSION

5.1 Conclusion

Proppant usage in hydraulic fracturing is getting more popular for well stimulation in the current oil and gas industry. Unfortunately, there is still no local manufacturer or supplier of proppant in Malaysia. This project gives new approach to Malaysia's sand industry for new alternative for the application of the abundant silica sand resources. This project can also introduce a substitute for the imported proppant that has been used by oil and gas companies for their operation on Malaysia.

Proppant is characterized by its physical properties and chemical composition. Several experiments have been conducted to analyze the characteristics of the local sand sample. However, the Geological Survey Reports obtained from Malaysia Mineral and Geosciences Department (JMG) have given positive indications on the possibility of Terengganu silica sand to be used as proppant.

Terengganu has the largest silica sand reserves in Peninsular Malaysia but there is still no exploitation of the silica sand from Terengganu. The geological survey works which have been conducted by JMG showed that the silica sand in Terengganu possesses **high silica content (>98%)** with suitable **particle size distribution (0.3 – 0.6 mm)** which is then agreed by the sieve analysis results carried out on the local sand sample. The reports have led this project to concentrate on the potential of silica sand in Terengganu and experiments have been conducted on sand samples taken from the sites. Based on the experiment results, the studies are deduced as below;

- Sample 2 and Sample 3 show good potential for possible use as proppant with certain limitations.

- From the early reports by JMG, both Sample 2 and 3 possess high purity of SiO2 which is >98% (Johari and Eki, 2001). Sample 2 has the mean value of 99.16% and Sample 3 has the mean value of 98.51%

- The sphericity and roundness for both local sand sample have the same range of 0.5 – 0.7 RS on the Krumbein Chart.

- The density and the turbidity of both local sand sample meet agree with the density and the turbidity of the commercially available proppant.

- Both Sample 2 and Sample 3 start to produce more than 10% fine under the pressure of 1000 psi and above. This means that these two samples could be used as proppant for reservoir with the pressure less than 1000 psi. For pressure above 1000 psi, the fines produced would fill the porous medium in between the sand particle hence the permeability will be reduced. This deceits the purpose of hydraulic fracturing.

- The permeability test contributes in calculating the conductivity of the sand samples. The conductivity of local sand is 16 – 20% lower than the commercial proppant. Even though the test is not conducted according to the recommended practice API RP 56, this shows good comparison in between commercial proppant (Sample 1) to possible local proppant (Sample 2, Sample 3).

Based on the results, it is possible for Malaysia to produce our own local proppant with some essential adjustments (Refer 5.2) on the sand prior to production in market. The abundant source of silica sand in Malaysia shows good potential of profitable business especially if the demand and cost of proppant in the market is higher than the cost of treating the sand in meeting the requirements of American Petroleum Institute (API) and International Standard Organization (ISO).

5.2 Recommendations

This report has provided an insight on proppant characteristics and several of experimental setups. Below are recommendations that could lead to the success of this project in future:

5.2.1 To obtain larger amount of sand sample representative.

Larger amount of sand sample would give better representation of the local sand. The sand sample should be taken from a few places to have a significant representation of the local sand of an area.

5.2.2 To coat the sand with resin for improved characteristics

Coating sand with resin could improve the roundness and sphericity of sand particle. Resin could provide better resistance for the sand on high closure stress. Furthermore, resin-coated sand can reduce the proppant flow back problem that can cause the fracture to close and reduce the permeability.

According to Sinclair *et al.* (2007) typical resins that are used during the coating process are epoxy, furan, phenolic resins or combinations of such resin. This process is also known as "hot coat" process.

First, the particulate substrate is heated to a desired temperature (e.g. about 400°F to about 450°F) and then the resin is added to the hot particulate substrate. Sinclair *et al.* (2007) suggested that the desired temperature is preferably above the melting point of the resin.

5.2.3 To coat sand with mullite

As discovered on Sample 1 which is treated with mullite, our local sand's strength can be improved with the presence of mullite. Besides improving the strength, coated-sand will also be protected from acidic environment as mullite is insoluble in acid, HF included where silica dioxide would dissolve in HF (Bowen *et al.*, 1924).

More studies should be conducted in the coating procedures and economic consideration of the treatment.

5.2.4 To collaborate with proppant testing company

Until today, there are few proppant testing companies which are active in the industries such as PropTester (United States of America), PANterra (The Netherlands), and FracTech Laboratories (England). If the university could have collaboration with a proppant testing company, tests can be done with standard procedures where the results would be more representative and reliable.

CHAPTER 6

REFERENCES

1 Anderson, R., Cooke, C., and Wendorff, C.:"Propping Agents and Fracture Conductivity," in *Recent Advances in Hydraulic Fracturing*: SPE (1989).

2 Aw, P.C.: "Geological Survey Report: Silica Sand Deposits at Batu Tampin and Kampung Meraga, Kemaman, Terengganu ": Jabatan Mineral dan Geosains Malaysia (1978).

3 Aw, P.C.:"Geological Survey Report: Silica Sand Deposits at Bukit Semanyok, Dungun, Terengganu," Jabatan Mineral dan Geosains Malaysia (1979).

4 Aw, P.C.:"Geological Survey Report: Silica Sand Deposits West of Kampung Kuala Abang, Terengganu," Jabatan Mineral dan Geosains Malaysia (1989).

5 Aw, P.C.:"Industrial Mineral Assessment Report: Silica Sand Deposit at Kampung Rantau Abang 'B', Terengganu," Jabatan Mineral and Geosains Malaysia (1989).

6 Bench Top Permeability System, BPS-805 Operator's Manual, Geosciences and Petroleum Department, Universiti Teknology PETRONAS (September 2009).

7 Bowen, N. L., Greig, J. W. and Zeiss, E. G.: "Mullite, a new silicate of alumina" (1924).

8 "Choosing Fracturing Sand to Optimize Permeability Achieved Vs Cost", Halliburton (2005).

9 Determination of Particle Size Distribution Laboratory Manual, Civil Engineering Department, Universiti Teknologi Petronas (July 2009).

10 Economides, M.J and Nolte, K.G.: "Reservoir Stimulation Handbook", Second ed. (1989).

11 Eki, A. and Johari, D.: "Kajian Tinjauan Kaolin, Lempung Bebola Dan Pasir Silika Di Kawasan Bahagian Kota Samarahan, Bintulu Dan Miri, Sarawak," Malaysia Minerals and Geoscience Department, 2001).

12 "Examples of Natural Sand Based Proppant", Halliburton Stimulation (2005).

13 “Hydraulic Fracturing”, Department of Petroleum Engineering, Harriot-Watt University. (Accessed on 2009)

14 "Industrial Mineral Production Statistics and Directory of Producers in Malaysia 2006," ed. Minerals and Geoscience Department Malaysia (2006).

15 "Industrial Mineral Production Statistics and Directory of Producers in Malaysia 2007," ed. Minerals and Geoscience Department Malaysia (2007).

16 Introduction to X-Ray Diffraction, Bruker AXS (2001)

17 Kaufman, P. et al.: " SPE 110697: Introduction New API / ISO Procedures for Proppant Testing”, Society of Petroleum Engineers, presented in *2007 SPE Annual Technical Conference and Exhibition* (Anaheim, California, USA, 2007).

18 Kazi, M. S.: “US 2007/0114029 A1: Hydraulic Fracturing Proppants and Methods of Use,” United States Patent (2007).

19 Kwan, P.T.:”The Mineral Industry of Malaysia 2006,”Geological Survey, US Department of Interior (accessed 24 February 2009) <minerals.er.usgs.gov/minerals/pubs/country>

20 Lunghofer, E. P.: "Hydraulic Fracturing Propping Agent ": Dresser Industries, Inc. (Dallas, TX) (1985).

21 Mullite, AzoMaterials, (accessed on 27 October 2009) < http://www.azom.com/Details.asp?ArticleID=925>

22 Natural Frac Sand, Halliburton (accessed on 25 February 2009) <www.halliburton.com>

23 Sinclair et al.:”US Patent 7244492 B: Soluble Fibers for Use in Resin Coated Proppant,” United State Patent (2007)

24 Proppant Technical Presentation and Theory, CarboCeramics (accessed on 24 February 2009). <www.carboceramics.com>

25 Proppant, Schlumberger (accessed on 24 February 2009) <www.slb.com>

26 Rach, M. N.:”Proppant in Great Demand; Production Constrained”, Red Orbit (accessed on 25 February 2009) <www.redorbit.com/news/display/?id=476272>

27 Schechter, R. S.: “Oil Well Stimulation,” 1st Edition, Prentice-Hall, Inc (1992).

28 Veatch, R.W Jr. et al.: "An Overview of Hydraulic Fracturing," in *Recent Advances in Hydraulic Fracturing*: SPE (1989).

29 Vincent, C. M.: “Optimization of Hydraulic Fracturing in CBM Wells”, CarboCeramics (2009).

30 Youngman, R., Okel, P., Akbar, S.: "Proppant Composition for Gas and Oil Well Fracturing," Fairmount Minerals, Ltd (2002).

APPENDICES

APPENDIX 1: PROJECT TIMELINE AND EXECUTION PLAN

1) PROJECT TIMELINE

Semester 1

PROJECT TIMELINE FOR SEMESTER 1																
NO	DETAIL/WEEK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	PROJECT TOPIC SELECTION															
2	PRELIMINARY RESEARCH WORK															
3	SUBMISSION OF PRELIMINARY REPORT						●									
4	PROJECT WORK CONTINUES															
	a) Literature review on proppant and its usage in hydraulic fracturing															
	b) Checking on Equipment Availability															
5	SUBMISSION OF PROGRESS REPORT															
6	SEMINAR (COMPULSORY)															
7	PROJECT WORK CONTINUES															
	a) Literature review on sand															
	a) Collecting sands sample															
	b) Lab Testing Planning															
8	SUBMISSION OF INTERIM REPORT												●			
9	ORAL PRESENTATION															●

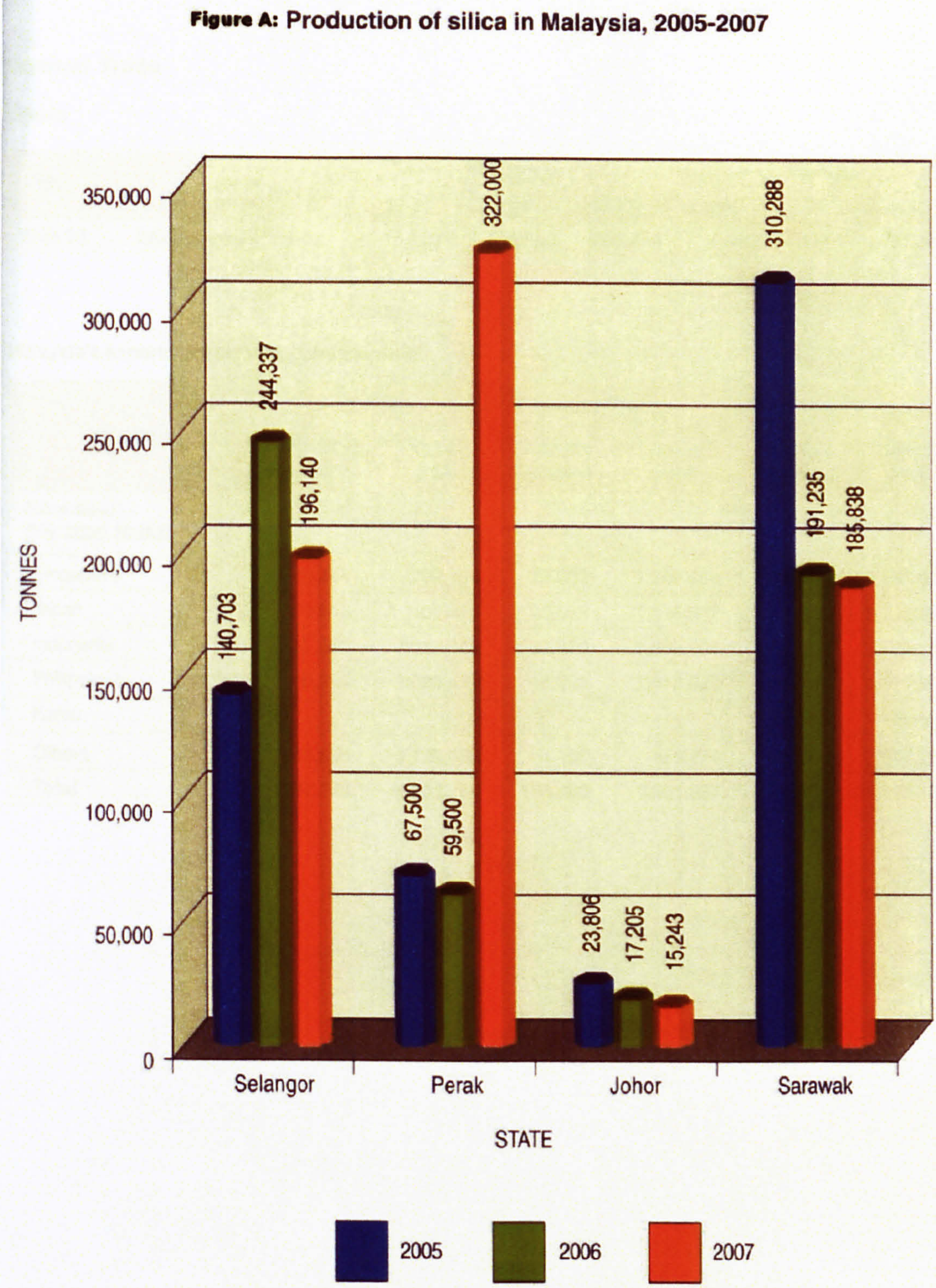
● Suggested milestone
Process

Semester 2

PROJECT TIMELINE FOR SEMESTER 2																		
N	DETAIL/WEEK	SEM BREAK	1	2	3	4	5	6	7	8	9	10	1	12	1	14	S	E
1	PROJECT WORK CONTINUES																	
	a) Particle Size Distribution																	
	b) Density and Porosity Determination																	
	c) Turbidity Determination																	
2	SUBMISSION OF PROGRESS REPORT 1					●												
3	PROJECT WORK CONTINUES																	
	b) Scanning Electron Micrograph (SEM)																	
4	SUBMISSION OF PROGRESS REPORT 2								●									
5	PROJECT WORK CONTINUES																	
	a) Crush Testing																	
	b) Permeability Test																	
6	PROJECT WORK CONTINUES																	
	a) X-Ray Diffraction (XRD)																	
	b) X-Ray Fluorescence (XRF)																	
7	POSTER EXHIBITION												●					
8	SUBMISSION OF DISSERTATION (SOFT BOUND)													●				
9	ORAL PRESENTATION															●		
10	SUBMISSION OF DISSERTATION (HARD BOUND)																	●

● Suggested milestone
Process
SW Study Week
EW Exam Week

APPENDIX 2



Source : Malaysian Mineral Yearbook 2007, JMG (2007)

APPENDIX 3

External Trade

Exports

H.S.	Commodity	tonnes			RM '000		
		2005	2006	2007p	2005	2006	2007p
2505.10	Silica & quartz sands	167,278	104,880	295,754	7,362	5,862	34,866

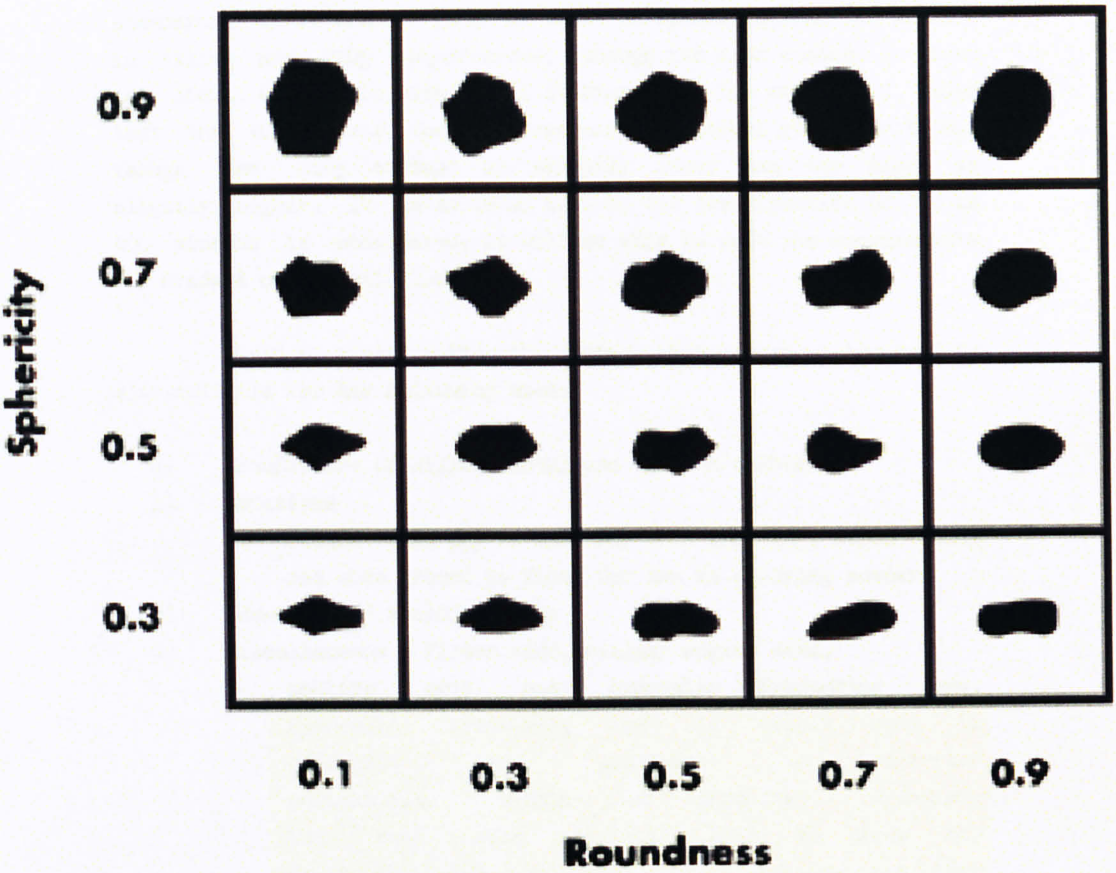
Malaysia's exports of silica sand, by country

Country	2005		2006		2007p	
	Quantity (tonnes)	Value (RM)	Quantity (tonnes)	Value (RM)	Quantity (tonnes)	Value (RM)
Silica sand (HS: 2505.10.000)						
Singapore	40,244	799,704	22,903	1,249,958	118,196	26,152,020
Japan	25,943	1 ,400,424	26,552	1,476,037	71 ,303	3,320,371
Indonesia	47,250	2,018,340	35,370	1,663,805	50,101	2,567,175
Philippines	40,286	2,020,639	18,900	1,016,820	25,540	1,195,709
Korea	-	-	-	-	27,923	792,527
Others	13,556	1,122,653	1,156	455,274	2,690	837,762
Total	**167,278**	**7,361,760**	**104,880**	**5,861,894**	**295,754**	**34,865,566**

Source : Malaysian Mineral Yearbook 2007, JMG (2007)

APPENDIX 4

Krumbein Roundness and Sphericity Chart



***Source: www.carboceramics.com**

APPENDIX 5

The silica sand of Kampung Kuala Abang is of consistent quality both physically and chemically. According to Malaysian standards, it is Grade B sand. It meets UK specifications for Grade A in silica and TiO_2 requirements, though its iron content is above the limit. Comparison with the US stantards, on the other hand, shows that the sand meets the requirements of optical glass for Fe_2O_3, though the SiO_2 content is slightly lower and the Al_2O_3 is slightly higher. It is believed that if the size fraction of 180 to 600 microns is considered, it will be able to meet the requirements for Grade A or optical glass.

Besides glass making the Kampung Kulau Abang silica sand is also suitable for the following uses:

a) Manufacture of silicon metal and silicon carbide

b) Abrasives

Silica sand may be used for sand blasting, stone-sawing and when ground to flour for use as scouring powder.

c) Foundary and moulding sands

d) Miscellaneous : filter sand, railway engine sand, poultry grid and hydraulic fracturing sand. Hydraulic fracturing sand is widely used in oilfields and gasfields to increase permeability within a producing formation. The sand acts as a prop to keep the fractures open so that oil and gas can move more easily (Carr 1971).

Discussion on Conservation and Exploitation

The silica sand under discussion meets the physical and chemical specifications for high grade glass sand. It is at least suitable for the manufacture of high grade domestic and decorative glassware (Grade B). If a narrow range of size fraction is selected, the silica sand may meet the requirements for optical glass.

Source: Jabatan Mineral dan Geosains Malaysia, Geological Survey Report, Page 9. (1989)

APPENDIX 6

Table 1. Typical Physical Properties of Brady-type Frac Sand*

TYPICAL PHYSICAL PROPERTIES OF BRADY-TYPE FRACTURING SAND[17] *						
	Recommended	API Mesh Size				
API Property	Limits	6/12**	8/16	12/20	16/30	20/40
Particle diameter range, μm	Standard	3,350 to 1,700	2,360 to 1,180	1,700 to 850	1,180 to 600	850 to 425
Sieve analysis, wt% retained						
Top sieve	0.1 maximum	0.0	0.0	0.0	0.0	0.1
Between primary sieves	90.0 minimum	95.7	93.1	91.0	98.5	91.6
Second and sixth sieves		4.2	6.6	8.5	1.0	8.0
Pan	1.0 maximum	0.1	0.3	0.5	0.5	0.4
Total		100.0	100.0	100.0	100.0	100.0
Krumbein shape factor						
Roundness	0.6 minimum	0.6	0.6	0.6	0.6	0.6
Sphericity	0.6 minimum	0.6	0.6	0.6	0.6	0.6
12/3 HCl/HF solubility, 30 minutes at 150°F, wt%	3.0 maximum	0.4	1.0	1.0	0.8	0.8
Silt and fine particle, FTU†	250 maximum	20	95	120	45	115
Crush resistance, % fines	Variable with size	17.9	13.4	15.5	8.3	11.4
generated at closure stress, psi		2,000	2,000	3,000	3,000	4,000
Particle density, lbm/gal	22.1 maximum	22.1	22.1	22.1	22.1	22.1
Bulk density, lbm/ft^3	105.0 maximum	95.5	98.0	99.9	101.1	100.5
Clustering, wt%	1.0 maximum	<1.0	<1.0	<1.0	0.0	0.0

*All tests performed according to Ref. 11 or 12. Sources include Hickory sandstone, aeolian dune sand, and Bidahochi formation. Values shown are averages of multiple production samples over a 4-year period.
**Not commercially available at this time.
†FTU = formazine turbidity units

Table 2. Typical Physical Properties of Ottawa-Type Frac Sand*

TYPICAL PHYSICAL PROPERTIES OF OTTAWA-TYPE FRACTURING SAND[17] *							
	Recommended	API Mesh Size					
API Property	Limits	12/20**	16/30	20/40	30/50	40/70	70/140
Particle diameter range, μm	Standard	1,700 to 850	1,180 to 600	850 to 425	600 to 300	425 to 212	212 to 106
Sieve analysis, wt% retained							
Top sieve	0.1 maximum	0.0	0.0	0.0	0.0	0.1	0.1
Between primary sieves	90.0 minimum	93.2	97.9	91.5	93.1	91.8	90.0
Second and sixth sieves		6.6	2.1	8.0	6.5	7.6	9.1
Pan	1.0 maximum	0.2	0.0	0.5	0.4	0.6	0.8
Total		100.0	100.0	100.0	100.0	100.0	100.0
Krumbein shape factor							
Roundness	0.6 minimum	0.7	0.7	0.7	0.7	0.7	0.6
Sphericity	0.6 minimum	0.7	0.7	0.8	0.8	0.7	0.7
12/3 HCl/HF solubility, 30 minutes at 150°F, wt%	3.0 maximum	1.5	1.0	1.0	0.9	1.2	2.5
Silt and fine particle, FTU	250 maximum	68	110	80	60	40	130
Crush resistance, % fines	Variable with size	5.4	1.6	4.0	3.3	3.4	2.5
generated at closure stress, psi		3,000	3,000	4,000	4,000	5,000	5,000
Particle density, lbm/gal	22.11 maximum	22.1	22.1	22.1	22.1	22.1	22.1
Bulk density, lbm/ft^3	105.0 maximum	95.5	98.6	102.7	103.0	102.7	103.0
Clustering, wt%	1.0 maximum	0.0	0.0	0.0	0.0	0.0	0.0

*All tests performed according to Ref. 11 or 12. Sources include Saint Peter, Jordan, Galesville, and Ironton sandstones. Values shown are averages of multiple production samples over a 4-year period.
**Available in limited quantities on special order only.

***Source : Recent Advances in Hydraulic Fracturing, SPE 1989**

APPENDIX 7

Permeability test result for Sample 1

Time (min)	K (mD)	Q (cc/min)	dP (psi)
0.50	7673.11	1.50	0.03
1.00	0.00	1.50	0.00
1.50	7798.84	1.50	0.05
2.00	0.00	1.50	0.00
2.50	7798.84	1.50	0.05
3.00	0.00	1.50	-0.01
3.50	8238.00	1.50	0.03
4.00	5336.05	1.50	0.07
4.50	7138.49	1.50	0.04
5.00	8448.74	1.50	0.05
5.50	7798.84	1.50	0.05
6.00	6336.56	1.50	0.06
6.50	2981.91	1.50	0.13
7.00	2253.00	1.50	0.17
7.50	2357.79	1.50	0.16
8.00	2112.19	1.50	0.18
8.50	1877.50	1.50	0.21
9.00	1843.36	1.50	0.21
9.50	1748.02	1.50	0.22
10.00	1609.28	1.50	0.24
10.50	1370.07	1.50	0.28
11.00	1513.21	1.50	0.26
11.50	1584.14	1.50	0.24
12.00	1559.77	1.50	0.25
12.50	1490.95	1.50	0.26
13.00	1351.80	1.50	0.29
13.50	1334.01	1.50	0.29
14.00	1283.35	1.50	0.30
14.50	1067.21	1.50	0.36
15.00	1067.21	1.50	0.36
15.50	984.32	1.50	0.39
16.00	844.87	1.50	0.46
16.50	938.75	1.50	0.41
17.00	881.61	1.50	0.44
17.50	913.38	1.50	0.42
18.00	1013.85	1.50	0.38
18.50	993.97	1.50	0.39
19.00	905.22	1.50	0.43
19.50	889.34	1.50	0.44
20.00	984.32	1.50	0.39

20.50	984.32	1.50	0.39
21.00	897.21	1.50	0.43
21.50	859.19	1.50	0.45
22.00	866.54	1.50	0.45
22.50	844.87	1.50	0.46
23.00	965.57	1.50	0.40
23.50	859.19	1.50	0.45
24.00	811.08	1.50	0.48
24.50	930.14	1.50	0.42
25.00	792.07	1.50	0.49
25.50	889.34	1.50	0.44
26.00	874.01	1.50	0.44
26.50	874.01	1.50	0.44
27.00	897.21	1.50	0.43
27.50	844.87	1.50	0.46
28.00	851.97	1.50	0.45
28.50	844.87	1.50	0.46
29.00	844.87	1.50	0.46
29.50	792.07	1.50	0.49
30.00	785.93	1.50	0.49
30.50	881.61	1.50	0.44
31.00	817.62	1.50	0.47
31.50	779.88	1.50	0.50
32.00	798.31	1.50	0.48
32.50	773.93	1.50	0.50
33.00	831.02	1.50	0.47
33.50	745.48	1.50	0.52
34.00	804.64	1.50	0.48
34.50	729.39	1.50	0.53
35.00	844.87	1.50	0.46
35.50	768.07	1.50	0.50
36.00	798.31	1.50	0.48
36.50	773.93	1.50	0.50
37.00	844.87	1.50	0.46
37.50	831.02	1.50	0.47
38.00	792.07	1.50	0.49
38.50	798.31	1.50	0.48
39.00	773.93	1.50	0.50
39.50	734.67	1.50	0.53
40.00	874.01	1.50	0.44
40.50	785.93	1.50	0.49
41.00	6336.56	1.50	-0.06
41.50	3072.27	1.50	-0.13
42.00	1987.94	1.50	-0.20
42.50	2304.20	1.50	-0.17

Permeability test result for Sample 2

Time (min)	K (mD)	Q (cc/min)	dP (psi)
0.50	1013.85	1.50	0.38
1.00	930.14	1.50	0.42
1.50	1152.10	1.50	0.34
2.00	1139.16	1.50	0.34
2.50	965.57	1.50	0.40
3.00	851.97	1.50	0.45
3.50	874.01	1.50	0.44
4.00	1013.85	1.50	0.38
4.50	713.98	1.50	0.54
5.00	734.67	1.50	0.53
5.50	1427.96	1.50	0.27
6.00	5069.25	1.50	-0.08
6.50	2413.93	1.50	-0.16
7.00	1584.14	1.50	-0.24
7.50	889.34	1.50	-0.44
8.00	560.14	1.50	-0.69
8.50	525.31	1.50	-0.74
9.00	662.65	1.50	-0.58
9.50	751.00	1.50	-0.52
10.00	779.88	1.50	-0.50
10.50	804.64	1.50	-0.48
11.00	897.21	1.50	-0.43
11.50	745.48	1.50	-0.52
12.00	734.67	1.50	-0.53
12.50	779.88	1.50	-0.50
13.00	792.07	1.50	-0.49
13.50	713.98	1.50	-0.54
14.00	689.69	1.50	-0.56
14.50	729.39	1.50	-0.53
15.00	859.19	1.50	-0.45
15.50	740.04	1.50	-0.52
16.00	667.01	1.50	-0.58
16.50	618.20	1.50	-0.63
17.00	548.03	1.50	-0.71
17.50	563.25	1.50	-0.69
18.00	557.06	1.50	-0.69
18.50	579.34	1.50	-0.67
19.00	734.67	1.50	-0.53
19.50	596.38	1.50	-0.65
20.00	569.58	1.50	-0.68

20.50	779.88	1.50	-0.50
21.00	859.19	1.50	-0.45
21.50	1102.01	1.50	-0.35
22.00	1662.05	1.50	-0.23
22.50	2896.71	1.50	-0.13
23.00	2157.13	1.50	-0.18
23.50	2534.62	1.50	-0.15
24.00	2204.02	1.50	-0.18
24.50	1987.94	1.50	-0.20
25.00	1448.36	1.50	-0.27
25.50	1778.68	1.50	-0.22
26.00	1662.05	1.50	-0.23
26.50	1987.94	1.50	-0.20
27.00	1843.36	1.50	-0.21
27.50	1635.24	1.50	-0.24
28.00	2413.93	1.50	-0.16
28.50	2357.79	1.50	-0.16
29.00	2896.71	1.50	-0.13
29.50	4827.85	1.50	-0.08
30.00	0.00	1.50	-0.01
30.50	7241.78	1.50	0.05
31.00	4408.04	1.50	0.09
31.50	2304.20	1.50	0.17
32.00	3270.48	1.50	0.12
32.50	1987.94	1.50	0.20
33.00	1843.36	1.50	0.21
33.50	1718.39	1.50	0.23
34.00	1584.14	1.50	0.24

Permeability Result for Sample 3

Time (min)	K (mD)	Q (cc/min)	dP (psi)
0.50	1165.34	1.50	0.33
1.00	1267.31	1.50	0.31
1.50	1427.96	1.50	0.27
2.00	1003.81	1.50	0.39
2.50	974.86	1.50	0.40
3.00	773.93	1.50	0.50
3.50	905.22	1.50	0.43
4.00	921.68	1.50	0.42
4.50	881.61	1.50	0.44
5.00	768.07	1.50	0.50
5.50	859.19	1.50	0.45
6.00	713.98	1.50	0.54
6.50	768.07	1.50	0.50
7.00	762.29	1.50	0.51
7.50	773.93	1.50	0.50
8.00	817.62	1.50	0.47
8.50	680.44	1.50	0.57
9.00	734.67	1.50	0.53
9.50	762.29	1.50	0.51
10.00	713.98	1.50	0.54
10.50	694.42	1.50	0.56
11.00	729.39	1.50	0.53
11.50	724.18	1.50	0.53
12.00	734.67	1.50	0.53
12.50	689.69	1.50	0.56
13.00	713.98	1.50	0.54
13.50	633.66	1.50	0.61
14.00	667.01	1.50	0.58
14.50	773.93	1.50	0.50
15.00	654.10	1.50	0.59
15.50	654.10	1.50	0.59
16.00	680.44	1.50	0.57
16.50	621.99	1.50	0.62
17.00	545.08	1.50	0.71
17.50	641.68	1.50	0.60
18.00	724.18	1.50	0.53
18.50	689.69	1.50	0.56
19.00	625.83	1.50	0.62
19.50	694.42	1.50	0.56
20.00	671.42	1.50	0.58

20.50	614.45	1.50	0.63
21.00	637.64	1.50	0.61
21.50	607.10	1.50	0.64
22.00	768.07	1.50	0.50
22.50	667.01	1.50	0.58
23.00	649.90	1.50	0.60
23.50	610.75	1.50	0.63
24.00	708.99	1.50	0.55
24.50	675.90	1.50	0.57
25.00	685.03	1.50	0.57
25.50	768.07	1.50	0.50
26.00	844.87	1.50	0.46
26.50	947.52	1.50	0.41
27.00	1045.21	1.50	0.37
27.50	866.54	1.50	0.45
28.00	866.54	1.50	0.45
28.50	851.97	1.50	0.45
29.00	729.39	1.50	0.53
29.50	745.48	1.50	0.52
30.00	768.07	1.50	0.50
30.50	625.83	1.50	0.62
31.00	719.04	1.50	0.54
31.50	645.76	1.50	0.60
32.00	662.65	1.50	0.58
32.50	671.42	1.50	0.58
33.00	699.21	1.50	0.55
33.50	645.76	1.50	0.60
34.00	708.99	1.50	0.55
34.50	658.34	1.50	0.59
35.00	694.42	1.50	0.56
35.50	645.76	1.50	0.60
36.00	685.03	1.50	0.57
36.50	637.64	1.50	0.61
37.00	680.44	1.50	0.57
37.50	649.90	1.50	0.60
38.00	641.68	1.50	0.60
38.50	654.10	1.50	0.59
39.00	667.01	1.50	0.58
39.50	680.44	1.50	0.57
40.00	563.25	1.50	0.69
40.50	654.10	1.50	0.59
41.00	586.04	1.50	0.66
41.50	528.05	1.50	0.73
42.00	560.14	1.50	0.69
42.50	633.66	1.50	0.61

43.00	685.03	1.50	0.57
43.50	582.67	1.50	0.66
44.00	658.34	1.50	0.59
44.50	633.66	1.50	0.61
45.00	662.65	1.50	0.58
45.50	625.83	1.50	0.62
46.00	699.21	1.50	0.55
46.50	589.45	1.50	0.66
47.00	621.99	1.50	0.62
47.50	625.83	1.50	0.62
48.00	607.10	1.50	0.64
48.50	621.99	1.50	0.62
49.00	694.42	1.50	0.56
49.50	649.90	1.50	0.60
50.00	599.91	1.50	0.65
50.50	596.38	1.50	0.65
51.00	569.58	1.50	0.68
51.50	579.34	1.50	0.67
52.00	557.06	1.50	0.69
52.50	586.04	1.50	0.66
53.00	582.67	1.50	0.66
53.50	599.91	1.50	0.65
54.00	621.99	1.50	0.62
54.50	586.04	1.50	0.66
55.00	582.67	1.50	0.66
55.50	579.34	1.50	0.67
56.00	566.40	1.50	0.68
56.50	603.48	1.50	0.64
57.00	557.06	1.50	0.69
57.50	589.45	1.50	0.66
58.00	582.67	1.50	0.66
58.50	614.45	1.50	0.63
59.00	596.38	1.50	0.65
59.50	589.45	1.50	0.66
60.00	614.45	1.50	0.63
60.50	536.43	1.50	0.72
61.00	548.03	1.50	0.71
61.50	603.48	1.50	0.64
62.00	545.08	1.50	0.71
62.50	566.40	1.50	0.68
63.00	557.06	1.50	0.69
63.50	560.14	1.50	0.69
64.00	551.01	1.50	0.70